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PHOTOGRAPH OF THE ORION NEBULOSITIES

By FRANK E. ROSS

ABSTRACT

A negative of the constellation of Orion, with its nebulosities, made at the Yerkes Observatory with a new wide-angle high-speed lens, is reproduced. The nebula is briefly described, and the contributions of Pickering, Barnard, and Wolf noted.

Plate II is from a negative of the constellation of Orion, made at the Yerkes Observatory, on January 6, 1927, the exposure time being five hours. Mr. A. Pogo assisted in the exposure. The scale is that of the original negative. The lens used had an aperture of 3 inches, and a focal length of 21 inches. It was made by C. A. R. Lundin, according to specifications of the writer. It is attached to the Bruce photographic telescope.

The exterior nebulosities shown on the print have been designated "the great curved nebula of Orion," a term originally used, I believe, by Professor E. E. Barnard. The nebula appears to have been photographed first by William H. Pickering, from Mount Wilson, in 1889, with a portrait lens of aperture 2.6 inches, and focal length 8.6 inches, the exposure time being three hours. So far as I know, no photograph or sketch was published. Pickering describes the nebula in considerable detail, in general agreement with Plate II.[1] Barnard, at the Lick Observatory, in 1893, obtained im-

[1] *Siderial Messenger*, **9**, 1, 1889.

pressions of the nebulosities, using a child's magic-lantern lens and the Willard portrait lens. He published a sketch of all of the nebulosity he was able to trace, together with a reproduction of a portion of one of his negatives showing its brightest part, near 56 and 60 Orionis. But the descriptions of neither Pickering nor Barnard do justice to the beauty and impressiveness of the nebula. There is no doubt that they were able to trace its general course, notwithstanding their very modest instrumental equipment. The details of structure, notably to the west of Rigel, and west of η Orionis, could not have been seen on their negatives, or they undoubtedly would have been described. From this viewpoint, it is puzzling to find that Pickering and Barnard both noted that the nebulosity extended, in its upper eastern branch, as far as γ Orionis. My negative indicates an ending at ω Orionis. Plate II shows a long straight vacant lane bordering the lower edge of Barnard's drawing of the extension in question, which may possibly have influenced the eye in extending the nebula. The present existence of the extension can be easily decided by more favorable exposures.

The nebula rests with its sweeping eastern branch upon the western edge of the Milky Way. The space between this branch and the condensed nebulosities, at θ and ζ Orionis, from 3° to 5° wide, is filled with an apparently structureless faint nebulosity. There appears to be a break in the nebulosity at κ Orionis. The northwestern end, to the west of η Orionis, has a great deal of curiously shaped detail, noted by Wolf (see below). To the west of Rigel, which is deeply involved in nebulosity, there is a very faint north-south band of nebulosity (noted by Pickering) separated from the main nebula by a dark region. Flanking this nebulosity on the east, near Rigel, from which it appears to be separated by a darker lane, is a beautiful nebula of considerable extent, which I have called the Witch's Head nebula. The print must be viewed south side up in order to see the resemblance, which is striking, even to the spectacles, to say nothing of the expression. This nebula showed as a very faint impression on Barnard's negative, and was not commented on. Credit for its discovery should, I think, be given to Dr. Max Wolf,[1]

[1] *Monthly Notices*, **65**, 528, 1905.

who publishes an excellent print of it. Wolf calls attention to the fact that it is of the same type as the nebula N.G.C. 1499, near ξ Persei, discovered by Barnard, and designates it as "the great nebula of ψ Eridani." It is listed in the *Index Catalogue* as No. 2118. Practically all of the nebulosities shown in Plate II are described by Wolf, the agreement being excellent.

YERKES OBSERVATORY
March 11, 1927

A STUDY OF THE INFRA-RED SOLAR SPECTRUM WITH THE INTERFEROMETER[1]

By HAROLD D. BABCOCK

ABSTRACT

Solar wave-lengths in the infra-red.—The solar spectrum in the interval λ 6868–λ 8980 has been photographed on plates sensitized with *neocyanin* through interferometers crossed with a concave grating. The *methods* and *apparatus* used are described, and also some of the precautions taken to avoid instrumental errors. The *wave-lengths* of 507 lines (Table II) were measured in terms of oxygen band lines due to terrestrial absorption, and are expressed on the *neon scale.*

Identification of solar lines.—Of the 507 *lines measured*, 176 are of solar origin; most of the remainder are probably lines of terrestrial water vapor. The measurements have been used for a revision of the identification of solar lines, but refined laboratory wave-lengths are much needed for further work. The more prominent solar lines still awaiting identification are listed in Table IV.

Differences between solar and terrestrial wave-lengths.—In the absence of precise laboratory data for vacuum spectra in the infra-red, the new solar wave-lengths are compared with interferometer measurements on the spectrum of a short iron arc at atmospheric pressure. This brings out clearly the correlation of multiplet grouping, excitation potential, and behavior under increased excitation with the combined influence of pressure displacement and pole effect. The data, though not definitive, are consistent with the gravitational displacement predicted by Einstein.

INTRODUCTION

The photographic difficulties which have somewhat retarded the progress of spectroscopy in the near infra-red have recently been markedly reduced. A new sensitizing material, neocyanin, makes it easy to obtain photographs which with dicyanin are troublesome and unsatisfactory. This is particularly important in investigations involving precise measurements, where instrumental changes and variations of observing conditions become a serious drawback, if the exposures are greatly prolonged. This paper presents the results obtained from a series of photographs of the solar spectrum covering the region λ 6868–λ 8980, neocyanin being used for wave-lengths greater than λ 7300.

The plates, which were prepared by Mr. C. E. K. Mees at the Research Laboratory of the Eastman Kodak Company, require a brief treatment with ammonia to make them ready for use. They keep indefinitely before this treatment and for at least two months afterward. Their maximum sensitivity is at λ 8300; their absolute

[1] *Contributions from the Mount Wilson Observatory*, No. 328.

speed is far higher than that of plates prepared with dicyanin; and, in addition, the negatives are free from fog and brilliant in contrast.

Although it has been found that terrestrial absorption lines dominate the infra-red solar spectrum, both in number and in average intensity, the several hundred recognized solar lines offer valuable opportunity for study. Some prominent unidentified solar lines call for new data from the laboratory, and accuracy of a comparatively high order is required in both solar and laboratory wave-lengths for fixing their origin. But beside the possibility of bringing to light elements hitherto unrecognized in the sun, it is perhaps more important to examine in greater detail the application of the fruitful theory of ionization to astrophysical problems, and to add to the impressive mass of data bearing on the existence of the Einstein effect the results of a study of that part of the spectrum in some ways peculiarly suitable for a test.

Grating measurements of the solar spectrum λ 6500–λ 9000 have been published by W. F. Meggers,[1] and F. S. Brackett[2] has studied the region λ 8900–λ 9850, but the methods employed were not sufficiently refined to yield wave-lengths accurate enough for any but the obvious identifications of solar lines. These papers are very useful for distinguishing between solar and terrestrial absorption lines and in providing wave-lengths sufficiently approximate for the reduction of observations made with the interferometer. The work of K. Burns[3] gives no wave-lengths in the infra-red region. No measurements made by the interference method in this part of the solar spectrum appear to have been published. It is hoped that the data now made available will be confirmed by other observers and that interpolation by the grating method will promptly be undertaken.

The observations presented here are part of a study of the whole solar spectrum photographically accessible, which has long been in progress at this Observatory. Results for the visible region, based on extensive measurements with gratings of high dispersion and with interferometers, will soon be published.

[1] *Publications Allegheny Observatory*, **6**, No. 3, 1919.

[2] *Mt. Wilson Contr.*, No. 197; *Astrophysical Journal*, **53**, 121, 1921.

[3] *Lick Observatory Bulletins*, **10**, 64 (No. 327), 1920.

METHOD

The Fabry-Perot interferometer with concave grating for auxiliary dispersion, which forms part of the equipment of the Pasadena Laboratory, has already been described.[1] This apparatus, so effective for the study of emission spectra, has proved suitable for extensive work on the solar spectrum as well. For this purpose, a coelostat was built in the instrument shop of the Observatory and mounted on the roof of the laboratory, where a second flat mirror directs the light vertically downward into the building upon a third mirror, which reflects it horizontally to the spectrograph. Space is lacking for the installation of a long-focus objective which would provide a large image of the sun. Instead, a lens of about 1-m focal length is used, and the measurements are made upon the spectrum of integrated sunlight. The lens, a visually corrected achromat of 9.5-cm clear aperture, produces a small image of the sun in focus on the etalon. The latter is so placed with respect to the concave mirror which projects the interference pattern on the slit that a real image of the sun 5 cm in diameter is formed on the ruled surface of the concave grating.

The integration of light over the whole disk necessarily produces spectral lines wider than those obtained from a restricted area of the disk. This disadvantage is not serious, however, since the lines in this part of the spectrum are inherently wide and the additional width is not relatively large. Quite apart from this effect, which is due primarily to the rotation of the sun, is the question of the comparability of wave-lengths derived from the center of the disk and from the entire disk. The well-known limb effect, although made somewhat less effective by the darkening at the limb, might be expected to produce slightly longer wave-lengths when integrated sunlight is used than when light is isolated from the center of the disk. An examination of the data available indicates that for the visible spectrum this difference can hardly exceed 0.001 A, a result confirmed by direct spectroscopic comparison. Data are lacking for such a comparison in the infra-red, but it is improbable that the wave-lengths of integrated sunlight can exceed those from the

[1] *Mt. Wilson Contr.*, No. 137; *Astrophysical Journal*, **46**, 138, 1917.

center of the disk by more than 0.002 or 0.003 A at λ 9000, which is near the limit of accuracy obtainable in that region.

The grating now in use was ruled in the instrument shop of the Observatory by Mr. Jacomini. It has 66,100 lines, spaced 600 to the millimeter, and the area of the ruled surface is 110 sq. cm. It gives exceptional brightness in the infra-red of one first-order spectrum, with some false light due to imperfection in the ruling. With the use of filters excellent contrast is obtained on photographs extending to λ 8980, which is the limit set by the space available for turning the camera.

Various filters were used, such as cobalt glass, Prussian blue in gelatin, and aqueous solutions of malachite green, with an ordinary red screen added for removing the short wave-lengths which they transmit. Occasionally the solution of malachite green was made dense enough to require no auxiliary screen. My thanks are due to Mr. Pettit for examining with a thermocouple the transmission of several screens over a wide range of wave-length. His observations, which will be published when completed, indicate that between λ 7000 and λ 9000 the cobalt glass Corning G585M, 3.5 mm thick, is the most efficient of the screens tested for the special purposes of this investigation.

The extent of spectrum to be photographed at one time and the curve of sensitivity of the emulsions to be used, together impose conditions on the properties of the screen which can be only approximately fulfilled. With some combinations of screens it was necessary to reduce the exposure of one part of the plate by means of a light shutter in front of the plateholder. In some instances a portion of one photograph was permitted to overexpose, and was subsequently reduced with potassium ferricyanide. For a few plates a region of under-exposure was copied twice by contact printing on emulsions of strong contrast, in order to make more lines available for measurement. In such cases the measurements on the original negative were carefully compared with those of the same lines on the copy in order to allow for any possible change of scale. Fifteen or twenty lines, inaccessible on certain original plates but measurable on others, were thus made to yield accordant results.

In the description of the spectrograph to which reference has

been made, it was stated that flat plates 10 inches long were used. Since that was written, the plateholder has been changed to accommodate plates 16 inches long. The radius of curvature of the focal surface is readily calculated from the elementary theory of the concave grating, details of which need not be repeated here. It turns out to be nearly 131 cm. Attention is directed to this point because in one description of this type of spectrograph it is erroneously stated that "the grating focused the spectra in a circle with its center at the grating and radius equal to the focal length of the grating."

A very satisfactory procedure consists in using three flat plates, each 5 inches long, held tangent to a form having the correct curvature. The residual errors in focal position of the plates are entirely negligible under these conditions, and the reduction of the measurements is facilitated.

The method of reduction developed and described in a previous paper[1] has been slightly modified to adapt it to the increased range of spectrum covered by each plate. The plate constant is now a constant only for the central section of the photograph; for the end sections it must be slightly increased, because the magnification of the spectrograph is slightly less at the ends of the plateholder than in the center. This variation is represented for each photograph by three straight lines on a diagram having wave-lengths for abscissae and values of the "constant" (or its four-place logarithm) as ordinates. From the radius of curvature of the focal surface the symmetrical relation between these lines is calculated once for all, so that it requires only a moment to construct the diagram after a value of the ordinate for any point is determined. From a large number of measurements corresponding to known focal settings of the spectrograph, an instrumental constant has been found by means of which the ordinate for the central section of the plate can be calculated with higher precision than it can be measured for a single plate. No measurements are required except those of the ring diameters themselves.

Etalons of 2.5, 5.0, 7.5, and 10.0 mm thickness have been used in this investigation, with four pairs of planes—two of fused quartz,

[1] *Mt. Wilson Contr.*, No. 202; *Astrophysical Journal*, 53, 43, 1921.

one of crystalline quartz, and one of glass. Most of the observations have been made with films of gold sputtered on the quartz planes, two different thicknesses of metal being used. Silver films were used for two photographs, and copper films were tried, but these gave a distinctly lower ratio of reflecting power to transmission coefficient than gold. The results are based entirely on photographs made with gold and silver.

The correction for change of phase has been found in the usual way by the use of etalons of different thickness having the same metallic films. For a 10-mm etalon with gold films the correction amounts to only −0.001 A for wave-lengths observed at λ 7700 in terms of standards at λ 6900, and it is a linear function of the wave-length. I am indebted to Mr. Pettit for thermocouple measurements of the transmission of one of my thinner gold films. He finds that the light transmitted falls uniformly from 27 per cent at λ 7000 to 15 per cent at λ 9000. Evidently no marked variation in the optical constants of gold occurs within this region, and no great phase change is to be expected.

The phase correction given above is in excellent agreement with a previous determination for a different pair of films, which were studied in the region λ 6000–λ 7438. It would appear that sputtered films of gold, like those of silver, are highly reproducible, at least with respect to the properties which determine the so-called "phase change." In fact, for silver, it has been found that the amount of the correction is the same for films two years old as for those a few hours old; for thick films as for thin ones; for those sputtered in one laboratory as for those made elsewhere. In all probability the same is true for gold.

During the course of the investigation the entire optical system was purposely displaced and readjusted with extreme care. The concave mirror used for projecting the interference pattern on the slit was replaced by another of nearly the same focal length, and every detail of the operation of the apparatus was thoroughly examined.

Diaphragms were used to prevent all useless light from reaching the etalon, and a water cell was usually inserted in the beam of light. The effect of exposing the etalon continuously to the solar

image under conditions distinctly less favorable than those regularly employed was tested by using the very fine line λ 6292, due to terrestrial oxygen, for a series of visual measurements of the thickness of the etalon. Seven sets of readings made at ten-minute intervals showed a steady increase in thickness, amounting to one part in one-and-a-half million at the end of an hour. The sunlight was then cut off, and a half-hour later a trial showed that the thickness had continued to increase at about the same rate. In making photographs of the infra-red spectrum, the total energy incident on the etalon was less than one-half of what it was in this test. The lines on long exposures appear as sharp, and give the same wave-lengths, as on the short ones.

The well-known difficulties of securing reliable comparison spectra for precise measurements of wave-length are no less troublesome in the infra-red region, where exposures are sometimes necessarily prolonged. Neither the method of simultaneous exposures nor that of successive exposures is satisfactory for use with the interferometer in this part of the spectrum; and the overlapping higher-order spectra are not available, because interferometers economical of infra-red light generally have too little reflecting power to produce good fringes in violet light.

Instead of employing directly either the primary standard or any of the adopted secondaries, it was decided to refer all measurements to the wave-lengths of selected absorption lines of terrestrial oxygen which have been well determined from secondary standards in the spectrum of neon. These oxygen lines offer definite advantages, since they are automatically present on photographs of the solar spectrum, under conditions of illumination identical with those obtaining for the solar lines. Furthermore, many of them are very sharp, and a thorough examination has shown[1] that they are constant in position within the errors of established methods of observation. The use made of them here confirms the reliability of both oxygen and water vapor lines, at least for solar altitudes greater than about 40°.

The work was done between June 9 and October 28, 1926, at different hours between 9:00 A.M. and 4:00 P.M. No evidence of

[1] *Mt. Wilson Contr.* No. 223; *Astrophysical Journal*, **55**, 321, 1922.

variability in position is shown by any of the observed wave-lengths, except that due to the motion of the apparatus with respect to the sun. Corrections for this motion ranging from −0.013 to +0.015 A were applied to the observed wave-lengths of all solar lines, and it is an indication of the accuracy of the results that the application of these corrections always increased the accordance of the data. In fact, one may readily distinguish between solar and terrestrial lines without using the rotation of the sun, by taking interferometer plates

TABLE I

WAVE-LENGTHS OF OXYGEN LINES USED AS STANDARDS; NEON SCALE

a-Band	*B*-Band		*A*-Band
6276.609	6868.915	6893.309	7676.563
6276.818	6869.093	6896.037	7677.618
6278.878	6870.946	6896.965	7682.756
6279.100	6871.285	6899.954	7683.800
6279.896	6872.247	6900.868	7689.177
6280.393	6872.843	6904.117	7690.217
6281.178*	6873.798	6905.023	7695.837
6281.956*	6874.653	6908.534	7696.868
6283.795*	6875.590	6909.431	
6287.747	6876.715	6913.200	
6289.397	6877.637	6914.090	
6290.222	6879.041	6918.122*	
6292.162*	6879.928*	6919.002*	
6292.957*	6883.832*	6923.302*	
6295.178*	6886.743	6924.172*	
6295.961*	6888.948		
6302.001	6889.903		
6305.810	6892.369		

at such hour angles and longitudes of the sun as to make use of the variation in the earth's motion with respect to the sun.

With the exception of three short gaps of about 200 A each, atmospheric lines suitable for use as secondary standards of wave-length are distributed over the entire region λ 6900–λ 9000. In contrast with the solar lines in this part of the spectrum, the atmospheric lines are notable for their great sharpness and blackness. They will undoubtedly prove of material assistance in further work.

In Table I are given the wave-lengths of some oxygen band lines which have been found particularly useful as working standards. Attention is specially directed to the fact that all the wave-lengths

communicated in this paper are independent of the adopted system of secondary standards in the iron-arc spectrum. It is now fully recognized that a slight revision of that system is necessary in order to make it accordant with the primary standard and with the adopted secondaries in the spectrum of neon. The latter, however, have shown no appreciable errors under the most critical scrutiny, and the adopted wave-lengths may be accepted with confidence. For this reason the data given in Tables I and II have been marked "neon scale," and it is hoped that they are free from systematic errors. New measurements of the wave-lengths of iron-arc lines have now been completed at this Observatory for the region λ 3400–λ 6750, which will soon be ready for publication.

The data given in Table I for lines in the *a*-band were derived from thirteen plates made with the interferometer and an equal number of grating plates. For each kind of exposure two entirely different instruments were used, one on Mount Wilson and one in the Pasadena Laboratory. In some cases the neon standards were used, while in others the revised values of the iron standards furnished the reference system. The agreement among the separate determinations is excellent, and the wave-lengths are probably reliable to the nearest 0.001 A. Lines marked with an asterisk are of slightly higher weight than the remainder.

The *B*-band lines of Table I were measured in terms of the best lines in the *a*-band on from six to thirteen interferometer plates. These plates also were made with two different instruments, as in the case of the *a*-band plates. The *B*-band lines were arranged in two groups corresponding to the two branches of the band, and the vacuum wave numbers were examined by taking first and second differences consecutively. The second differences are very accordant, the most probable value being $0.518\ cm^{-1}$ with a probable error of ±0.002. On the wave-length scale this corresponds to an uncertainty of about ±0.001 A in the relative values, which is nearly the same as the uncertainty in the absolute values of the wave-lengths.

The relative values of the best lines in the *B*-band have been further studied by using these lines as standards for determining the thicknesses of the etalons in the regular course of reduction of the

infra-red photographs. When the thickness is found from ten or twelve such lines, the probable error in the mean value is somewhat less than one part in ten million, and no systematic deviations are shown by the individual lines.

The *A*-band lines given in Table I were measured in terms of the *B*-band on twelve excellent interferometer plates made with four different lengths of etalons and three different pairs of films, both gold and silver. The variety of instrumental equipment used and the accordance of the results inspire confidence in the reliability of these working standards. Measurements made in terms of these *A*-band lines are in excellent agreement with those which are referred directly to the *B*-band.

Much of the measurement represented in this paper has been done under my direction by Mr. W. P. Hoge, and it is a pleasure to acknowledge my appreciation of his interested co-operation. Part of the photographs have been measured in duplicate and others solely by myself. The accordance of the measurements is closer than the nature of the lines would lead one to expect, even the wide solar lines showing accidental errors of only a few thousandths of an angstrom. As examples, the results from individual photographs are given below for the atmospheric line λ 8329 and for two solar

λ 8329.685	λ 8085.183	λ 8515.124
8329.681	8085.185	8515.122
8329.685	8085.173	8515.117
8329.678	8085.174	8515.123
8329.678	8085.174	8515.123
8329.679	8085.168	8515.117
8329.673	8085.171	8515.124
8329.681	8085.164	8515.116
8329.683	8085.175	8515.132
8329.688	8085.177	8515.120
8329.689	8085.176	8515.115

iron lines λ 8085 and λ 8515. These lines were not specially selected and are typical of the material in Table II. For lines observed on ten plates, the average wave-lengths generally have probable errors somewhat less than ±0.001 A, so that the probable error of a single determination may be taken as ±0.003 or 0.004 A as a rule.

Table II, to which reference has already been made, gives in

TABLE II

SOLAR SPECTRUM WAVE-LENGTHS; NEON SCALE

λ	Int.	Substance	No. Obs.	λ	Int.	Substance	No. Obs.
6868.915.....	7	A	4	7011.323.....	2	A	7
6869.093.....	6	A	4	7016.442.....	3	Fe, A	5
6870.946.....	8	A	4	7022.958.....	2	Fe	5
6871.285.....	10	A	4	7023.503.....	2	A	5
6872.247.....	11	A	8	7027.477.....	2	⊙, A	4
6872.843.....	12	A	8	7034.910.....	2N	⊙	4
6873.798.....	12	A	8	7039.793.....	1N	A	8
6874.653.....	13	A	8	7050.853.....	0	A	8
6875.590.....	13	A	8	7052.776.....	1	A	6
6876.715.....	13	A	8	7057.005.....	0N	A	2
6877.637.....	12	A	8	7065.647.....	1	A	3
6879.041.....	12	A	9	7068.423.....	2	Fe	2
6879.928.....	6	A	13	7084.975.....	2N	Co	4
6883.832.....	10	A	13	7088.153.....	00N	A	1
6885.754.....	11	A, Fe	9	7090.390.....	2	Fe	7
6886.743.....	12	A	9	7122.207.....	4	Co, Ni	8
6888.948.....	13	A	9	7130.925.....	3	Fe	8
6889.903.....	14	A	7	7132.983.....	1	Fe	3
6892.369.....	14	A	7	7148.149.....	3N	Ca	8
6893.309.....	15	A	8	7158.775.....	0N	A	1
6896.037.....	14	A	8	7162.041.....	00N	A	1
6896.965.....	15	A	8	7164.415.....	2	Fe, A	2
6899.954.....	14	A	8	7167.904.....	4N	A	6
6900.868.....	15	A	8	7172.713.....	1	A	1
6904.117.....	14	A	8	7181.509.....	2	A	1
6905.023.....	14	A	8	7184.526.....	4	A	1
6908.534.....	13	A	8	7191.493.....	6N	A	2
6909.431.....	13	A	8	7195.044.....	2	A	3
6913.200.....	11	A	7	7195.794.....	0N	A	1
6914.090.....	11	A	7	7197.865.....	1N	A	1
6914.564.....	4	Ni	12	7198.437.....	2	A	1
6916.677.....	2	Fe	8	7201.201.....	4	A	1
6918.122.....	9	A	12	7202.206.....	1N	Ca	1
6919.002.....	9	A	12	7204.306.....	5	A	3
6923.302.....	9	A	12	7206.420.....	6	A	3
6924.172.....	9	A	12	7207.396.....	1	Fe	2
6928.728.....	4	A	2	7209.504.....	3	Ti, A	8
6929.598.....	4	A	1	7211.202.....	1	A	2
6934.421.....	2	A	1	7216.527.....	2	A	7
6935.283.....	2	A	1	7223.636.....	3	A, Fe	6
6937.702.....	2N	A	4	7227.493.....	3	A	8
6943.801.....	3	A	6	7232.256.....	1	A	2
6945.210.....	4	Fe	7	7232.901.....	3	A	4
6947.543.....	5	Fe, A	6	7236.136.....	1	A	10
6959.453.....	3	A	8	7239.838.....	1	A, Fe	2
6961.261.....	4	A	8	7243.700.....	2	A	1
6977.469.....	3	Fe, A	1	7245.676.....	2	A	9
6978.861.....	2	Fe	4	7247.210.....	1N	A	5
6986.578.....	3N	A	9	7248.922.....	0N	A	3
6988.987.....	3	A	9	7250.216.....	1N	A	3
6993.521.....	2	A	4	7252.378.....	2N	A	1
6998.962.....	2	A	1	7253.723.....	2	A	1
7005.903.....	1	⊙	1	7257.371.....	00	A	3

TABLE II—*Continued*

λ	Int.	Substance	No. Obs.	λ	Int.	Substance	No. Obs.
7257.933.....	1N	A	1	7555.608.....	2	Ni	8
7260.731.....	0	A	4	7568.906.....	1	Fe	9
7261.457.....	∞N	A, Fe	2	7574.046.....	1	Ni	8
7262.973.....	0	A	3	7583.796.....	1	Fe	10
7265.594.....	5	A	4	7586.025.....	2	Fe	7
7269.752.....	∞N	A	3	7593.699.....	3	A	4
7272.973.....	5N	A	9	7593.851.....	0	A	1
7275.398.....	2N	A	5	7593.990.....	3	A	2
7277.391.....	2N	A	1	7594.293.....	0	A	1
7282.299.....	1N	A, Fe	2	7594.503.....	6	A	3
7287.378.....	2N	A	7	7594.974.....	4	A	1
7288.119.....	1	A	1	7595.780.....	5	A	2
7290.414.....	3N	A	4	7597.433.....	16	A	1
7303.197.....	2	A	4	7598.004.....	0	A	1
7304.173.....	3N	A	5	7612.054.....	23	A	1
7308.760.....	1	A	2	7613.181.....	19	A	1
7309.518.....	2N	A	6	7615.038.....	17d?	A	2
7312.618.....	1	A	2	7616.134.....	10	A	2
7315.516.....	0	A	4	7616.977.....	2	Ni	2
7318.688.....	1	A	2	7619.212.....	1	Ni	4
7323.972.....	1	A	4	7620.987.....	15d?	A	1
7326.164.....	0	Ca	3	7623.288.....	22d?	A	1
7327.370.....	1	A	1	7624.486.....	23d?	A	1
7330.857.....	1N	A	5	7625.350.....	0	A	1
7333.683.....	1	A	5	7627.045.....	24	A	1
7335.334.....	1	A	4	7628.227.....	25	A	1
7343.950.....	0	A	1	7630.237.....	0	A	2
7344.767.....	0	A	1	7631.019.....	24	A	1
7349.490.....	0	A	1	7632.163.....	25	A	1
7355.893.....	1	Cr	1	7634.166.....	0	A	2
7360.346.....	1	A	1	7635.189.....	24	A	1
7369.208.....	1	A	2	7636.310.....	25	A	1
7383.722.....	1	A	2	7637.174.....	0	A	1
7389.391.....	2	Fe	6	7638.302.....	0	A	5
7393.610.....	2	Ni	7	7639.577.....	22	A	1
7400.184.....	1	Cr	3	7640.693.....	23	A	1
7405.790.....	1	Si	4	7642.644.....	0	A	4
7409.355.....	1	Ni	1	7644.195.....	18	A	1
7411.158.....	1	Fe	6	7645.310.....	19	A	1
7414.512.....	1	Ni	5	7647.191.....	0	A	3
7415.957.....	1	Si	3	7649.032.....	15	A	1
7418.674.....	0	Fe	1	7649.583.....	0	A	1
7422.286.....	1	Ni	4	7650.126.....	16	A	1
7423.509.....	1	Si	4	7654.076.....	12	A	2
7440.915.....	1	Fe?	1	7655.178.....	13	A	2
7445.755.....	2	Fe	4	7657.605.....	2	Mg	4
7462.342.....	2	Cr, Fe+?	4	7659.350.....	9	A	2
7491.652.....	1	Fe	6	7659.898.....	0	⊙	1
7495.076.....	2	Fe	5	7660.440.....	10	A	3
7507.276.....	1	Fe	2	7661.196.....	1	Fe	2
7511.030.....	2	Fe	4	7664.297.....	1	Fe	4
7522.782.....	1	Ni	4	7664.880.....	6	A, K	1
7525.115.....	1	Ni	5	7665.938.....	6	A	3
7531.152.....	2	Fe	5	7670.600.....	5	A	5

TABLE II—*Continued*

λ	Int.	Substance	No. Obs.	λ	Int.	Substance	No. Obs.
7671.664	5	A	5	7937.149	3	Fe	10
7676.563	4	A	11	7941.096	1	Fe	4
7677.618	4	A	11	7944.001	2	⊙	8
7680.267	1	Mn	7	7945.857	2	Fe	11
7682.756	3	A	12	7958.491	1	A	7
7683.800	3	A	12	7960.734	1	A	6
7689.177	2	A	12	7968.122	0	A	4
7690.217	2	A	12	7971.520	0	A	4
7691.561	2	A	8	7984.343	1	A	5
7695.837	0	A	11	7994.488	1	Fe, Ni	3
7696.868	0	A	11	7998.952	2	Fe	4
7698.977	5	K	14	8000.303	2	A	4
7702.736	0	A	2	8007.470	1d?	Co? A	3
7703.754	0	A	2	8012.940	1	A	5
7710.367	1	Fe	4	8028.327	1	Fe, Ni	1
7711.737	1	Fe+	1	8028.542	1	A	1
7714.309	3	Ni	11	8034.293	1	A	3
7715.577	1	Ni	1	8036.459	1	A	3
7723.211	1	Fe	3	8039.598	1	A	3
7727.616	3	Ni	11	8045.532	1	A	1
7742.722	2	Fe	8	8046.056	2	Fe	10
7748.284	2	Fe	7	8047.626	1	Fe	4
7748.894	2	Ni	7	8075.161	0	Fe	3
7751.117	0	Fe	3	8085.175	2	Fe	11
7771.954	2	O	5	8090.464	∞N	⊙	2
7774.177	2	O	4	8093.236	0	Si?	2
7775.394	1	O	3	8094.269	∞	A	2
7780.567	3	Fe	11	8096.584	1	A	2
7788.933	2	Ni	11	8096.876	0	Fe	2
7797.587	2	Ni	10	8103.169	0	A	1
7799.995	0	⊙	3	8107.841	1	A	7
7807.915	1	Fe	10	8110.570	0	A	2
7832.207	2	Fe	10	8112.400	0	A	2
7836.139	0	⊙	1	8113.638	0	A	2
7849.984	1	⊙	4	8113.948	1	A	2
7855.392	0	Fe	3	8118.912	1	A	2
7866.070	0	A	1	8120.662	1	A	2
7872.789	1	A	1	8121.500	1	A	2
7880.709	1	A	1	8122.580	2	A	2
7887.117	1	A	6	8125.444	1	A	7
7889.340	0	A	2	8126.854	1	A	7
7891.900	1	A	4	8130.016	1	A	2
7893.511	2	A	7	8130.234	∞	A	2
7895.515	2	A	4	8130.459	2	A	3
7896.035	2	A	4	8131.214	1	A	2
7901.780	3	A	9	8133.208	0	A	2
7908.750	2	A, Co?	7	8133.560	0	A	2
7912.869	1	Fe	5	8133.774	5	A	3
7915.633	2	A	2	8135.047	5	A	5
7918.383	1	Si	7	8136.208	1	A	2
7920.664	1	A	6	8136.528	2	A	2
7924.348	2	A	4	8139.718	2	A	6
7928.617	2	A	8	8140.668	5	A	4
7932.351	2	Si?—	9	8141.936	4	A	5

TABLE II—*Continued*

λ	Int.	Substance	No. Obs.	λ	Int.	Substance	No. Obs.
8143.794.....	1	A	7	8233.905.....	5	A	10
8144.193.....	0	A	2	8234.627.....	1	A	3
8146.214.....	2	A	7	8237.341.....	3	A	8
8147.185.....	2	A	3	8239.139.....	0	Fe	1
8148.084.....	0	A	2	8239.925.....	3	A	5
8148.387.....	3	A	5	8243.136.....	0	A	2
8149.273.....	1	A	2	8243.481.....	5	A	5
8149.692.....	3	A	2	8248.140.....	0	Fe	3
8149.876.....	1	A	1	8248.801.....	0	⊙	3
8152.498.....	4	A	4	8252.727.....	2	A	11
8153.702.....	2	A	2	8256.514.....	8	A	8
8154.405.....	1	A	1	8259.692.....	4	A	11
8154.662.....	5	A	2	8263.446.....	3	A	11
8158.019.....	6	A	8	8272.041.....	4	A	12
8161.436.....	8	A	5	8274.353.....	8	Fe? A	6
8161.977.....	3	A	1	8276.519.....	4	A	1
8162.349.....	8	A	3	8276.676.....	4	A	1
8164.530.....	10	A	4	8279.600.....	5	A	11
8165.334.....	1	A	2	8282.022.....	8	A	8
8168.825.....	4	A	1	8287.944.....	8	A	5
8169.386.....	2	A	2	8289.533.....	4	A	9
8169.990.....	8	A	2	8293.526.....	∞	Fe	2
8174.678.....	1	A	1	8294.164.....	4	A	2
8176.976.....	10	A	6	8294.536.....	2	A	2
8177.934.....	4	A	2	8295.292.....	0	A	2
8178.494.....	2	A	2	8300.406.....	3	A	11
8179.046.....	4	Fe? A	1	8304.302.....	1	A	8
8181.847.....	6	A	7	8305.092.....	5	A	4
8183.274.....	3	Na	2	8311.955.....	2	A	4
8186.371.....	5	A	9	8313.874.....	0	A	4
8189.271.....	8	A	7	8316.224.....	1	A	10
8193.113.....	7	Co? A	7	8318.139.....	2	A	11
8194.835.....	2	Na	12	8321.247.....	2	A	2
8197.702.....	8	A	7	8321.564.....	4	A	2
8198.995.....	1	A	3	8327.060.....	2	Fe	10
8199.988.....	2	A	3	8329.682.....	3	A	11
8200.695.....	3	A	6	8331.927.....	1	Fe	2
8204.807.....	1	A	3	8332.141.....	1	A	1
8207.747.....	1	Fe	3	8333.584.....	2	A	8
8209.560.....	2	A	3	8335.178.....	∞	⊙	2
8210.321.....	2	A	3	8335.506.....	1	A	3
8212.132.....	4	A	10	8339.035.....	2	A	3
8213.037.....	3	⊙	2	8339.403.....	0	Fe	1
8218.112.....	5	A	11	8342.289.....	1	A	7
8200.393.....	2	Fe	7	8346.131.....	0N	⊙	3
8221.553.....	4	A	8	8349.150.....	1	A	1
8223.990.....	5	A	11	8349.385.....	0	A	1
8224.462.....	1	A	2	8353.643.....	1	A	6
8225.690.....	2	A	3	8357.041.....	1	A	10
8226.963.....	10	A	4	8357.447.....	0	A	1
8228.738.....	4	A	1	8362.003.....	0	A	1
8229.761.....	3	A	5	8362.296.....	0	A	2
8231.303.....	6	A	1	8365.640.....	1	Fe	6
8231.683.....	4	A	1	8367.333.....	2	A	10

TABLE II—*Continued*

λ	Int.	Substance	No. Obs.	λ	Int.	Substance	No. Obs.
8373.712.....	1	A	7	8710.393.....	0	Fe	3
8376.384.....	1	A	2	8712.679.....	00	⊙	1
8387.783.....	3	Fe	11	8713.214.....	00	Fe	1
8394.014.....	0	A	1	8717.832.....	0	⊙	4
8397.154.....	0	A	2	8728.022.....	0	⊙	4
8405.390.....	00N	A	1	8736.043.....	1	⊙	5
8408.759.....	0	A	2	8742.466.....	1	—, Si	4
8412.356.....	0	Ti	1	8752.024.....	1	Si	4
8415.438.....	0	A	3	8757.195.....	1	Fe	3
8426.518.....	0	Ti	4	8763.974.....	1	Fe	4
8434.969.....	1	Ti	5	8772.878.....	0	⊙	3
8435.656.....	1	Ti	4	8773.909.....	0	⊙	3
8439.583.....	0	Fe	9	8790.456.....	1	Fe	2
8460.252.....	0	A	1	8793.346.....	1	Fe	2
8468.420.....	2	Fe, Ti	10	8804.641.....	0	Fe	2
8471.733.....	00	Fe	1	8806.768.....	4	Mg	3
8497.003.....	0	Fe	1	8824.233.....	2	Fe	4
8498.061.....	12	Ca+	4	8838.442.....	1	Fe	2
8514.081.....	1	Fe	9	8846.748.....	00	Fe	1
8515.121.....	0	Fe	11	8862.564.....	0	Ni	1
8526.674.....	0	Fe	8	8866.937.....	1	Fe	2
8542.131.....	16	Ca+	6	8868.444.....	0	⊙	1
8556.795.....	1	Si?	9	8879.321.....	1	A	2
8582.271.....	1	Fe	8	8892.714.....	0	A?	2
8592.968.....	00	Fe	2	8912.100.....	0	⊙	2
8595.967.....	00	⊙	1	8917.517.....	0	A	1
8598.832.....	00	Fe	2	8920.028.....	0	Fe? A?	1
8611.813.....	1	Fe	8	8923.548.....	00	⊙	1
8613.943.....	00	⊙	1	8927.388.....	00	⊙	2
8616.277.....	0	Fe,—	3	8929.062.....	1	A, Fe?	1
8621.619.....	1	Fe	9	8930.260.....	0	A	1
8648.472.....	2	⊙	8	8934.100.....	1	A	2
8662.175.....	15	Fe, Ca+	4	8940.216.....	0	A	2
8674.756.....	1	Fe	8	8952.172.....	0	A	1
8679.652.....	00	⊙	1	8958.399.....	1	A	2
8686.370.....	00	⊙	2	8971.567.....	3	A	1
8688.642.....	2	Fe	6	8980.519.....	4	A	1
8699.459.....	1	Fe	5				

the first column the wave-length on the neon scale; in the second column, the intensity; in the third, the identification; and in the fourth, the number of plates on which the line was observed. When two substances are given for the same line, the symbol of the predominant one is sometimes underlined. Solar lines of unknown origin are indicated by the symbol ⊙. The intensities are from Rowland's table as far as λ 7330, and from the table of Meggers[1] thereafter. In the case of those atmospheric lines for which Meggers

[1] *Loc. cit.*

gives a variable intensity, only his greatest value has been entered, since the variations on my plates were not particularly noticeable. With some changes which are discussed below, the identifications have been taken from Meggers.

As noted above, corrections for motion in the line of sight have been applied to all solar wave-lengths in Table II. Corrections for atmospheric dispersion were found to be negligible throughout the investigation.

DISCUSSION

Comparison of the wave-lengths in Table II with those in Rowland's table shows a systematic difference in good agreement with that to be expected. The corrections required to transform the Rowland system into the international system range from −0.247 A at λ 6900 to −0.300 A at λ 7330, with evidence of numerous accidental errors much greater than those in the region of shorter wave-lengths. These are naturally to be expected when the difficulties which were faced by Professor Rowland in photographing the deep red are recalled. A more complete study of the differences between the Rowland and international systems, covering the entire Rowland table, is in progress at this Observatory and will soon be ready for publication.

The paper of Meggers to which reference has already been made furnishes the only other wave-lengths available for extended comparison with the data gathered here. The agreement turns out to be only approximate—a natural result, no doubt, of the method which he used. From λ 6900 to λ 8000 his wave-lengths are systematically longer than mine by an average of about 0.025 A, but within these limits the correction curve has six maxima. The irregularity of the corrections is further indicated by the following average values:

λ	Correction
7350	−0.065 A
7850	− .060
8050–8200	.000
8290	+ .045
8420	.000
8670	+ .070
8780	+ .035
8950	+0.075

Superposed on these systematic errors are accidental errors amounting frequently to ±0.02 A.

The correction curve was plotted and used for a revision of the identification of solar lines, the first results being collected in Table III. All the solar lines in Meggers' table not given in Table II of this paper were revised by the curve and compared with the available

TABLE III

SUGGESTED CHANGES IN PUBLISHED IDENTIFICATIONS OF SOLAR LINES

λ	Int.	Identification	Revision	λ	Int.	Identification	Revision
6920.13...	oo	.....	Cu?	7447.91..	oo	Mn?	Mn
6922.25...	oo	Co? A	Co, A	7449.34..	oo	.....	Fe+
6933.02...	oo	.....	Fe	7462.33..	2	Cr	Cr, Fe+?
7011.22...	ooo	Fe	.....	7515.85..	oo	.....	Fe+, Mn?
7011.33...	2	A	Fe, A	7533.39..	oo	—Co?	Fe+
7024.64...	o	Fe, Ni?	Fe	7551.12..	ooo	.....	Mn?
7024.86...	o	.....	Ni?	7578.77..	ooo	.....	Zn
7028.62...	ooo	Ni	.....	7655.44..	ooN	A	A, Fe+
7037.21...	o	A, Ni?	A, Ni	7711.74..	1	.....	Fe+
7141.54...	ooo	Ni?	Ni	7764.58..	ooo	Mn	.....
7164.43...	3	Fe, A?	Fe? A?	7877.05..	ooo	.....	Mg+?
7181.96...	o	Fe? Ni	Fe, Ni?	7877.46..	ooo	.....	Co
7191.65...	ooo	Fe?	Fe	7896.40..	oo	.....	Mg+?
7222.39...	oo	.....	Fe+	7908.75..	o–2	A, Co?	A, Co
7224.46...	oo	.....	Fe+	7949.15..	ooo	Ti? A	Ti, A
7285.28...	o	.....	Co	8085.44..	ooo	A?	A? Co?
7285.37...	ooo	Co?	.....	8112.15..	oo	.....	Co
7291.44...	o	Ni	Ni?	8179.05..	2–4	Fe? A	Fe, A
7295.03...	o–1	A, Fe?	A, Fe	8395.10..	ooo	A? Fe?	A? Fe
7301.55...	ooo	.....	Fe+	8417.23..	ooo	A, Ni?	A, Ni
7308.05...	ooo	.....	Fe+	8468.42..	2	Fe	Fe, Ti
7310.18...	oo–o	A	A, Fe+	8710.39..	o	Fe	Fe?
7320.67...	o	Fe	Fe, Fe+	8929.04..	1	A, Fe?	A, Fe
7363.97...	ooN	Ti	Ti?				

laboratory data. The first column of Table III gives the revised value of Meggers' wave-length; the second states the intensity which he assigned; and the third, his identification; while in the fourth column suggested changes are indicated.

At this point it is well to remark on the need for improved laboratory data in the infra-red region. The existing tables of arc spectra show discrepancies which frequently amount to 0.05 A, and in some cases to nearly 0.1 A. Even with accurate data on the solar spectrum available, the difficulties of identification are considerable when the basis of terrestrial wave-lengths is so insecure. Relative

intensities of lines, and especially relative excitation potentials or multiplet groupings, assume first importance in the solution of this problem; but such information is too often lacking. In addition it may be noted that very little has been published on the infra-red spectra of ionized atoms which are of astrophysical importance.

In Table IV are collected all the stronger unidentified solar lines between λ 6900 and λ 9000. Wave-lengths found by the interference method are given to the third decimal; for other lines the

TABLE IV

STRONGER UNIDENTIFIED SOLAR LINES BETWEEN λ 6900 AND λ 9000

λ	Int.	λ	Int.	λ	Int.
6911.50	0	7588.32	0	8248.801	0
6976.52	0	7659.14	1	8335.178	00
7005.903	1	7659.91	0	8346.131	0N
7012.61	0	7669.66	0	8502.23	0
7017.35	0	7691.561	2	8536.16	0
7017.66	0	7619.06	0	8648.472	2
7032.32	0	7799.995	0	8717.832	0
7034.910	2	7835.31	0	8728.022	0
7127.54	0	7836.139	0	8736.043	1
7165.55	0	7849.984	1	8772.878	0
7207.11	2	7930.82	0N	8773.909	0
7282.82	0	7944.001	2	8868.444	0
7351.11	0	8035.62	0	8912.100	0
7387.69	1N	8098.71	0N	8974.77	1
7440.88	1	8213.037	0–3		

revision of Meggers' value is given. An attempt has been made to examine the behavior of these lines in the spectra of sun-spots, but for most of them definite results have not yet been found. A few lines are clearly much weakened in the spot spectrum, which indicates that they should be sought among the spectra of ionized elements or among the high-temperature lines of arc spectra.

In Table V the solar wave-lengths from Table II are compared, as far as possible, with the iron-arc wave-lengths obtained with the interferometer by Meggers and Kiess.[1] The third column of the table shows the differences, sun *minus* arc; the fourth and fifth columns give the excitation potential[2] and the multiplet designation,[3]

[1] *Scientific Papers of the Bureau of Standards*, **19**, 273 (No. 479).

[2] Unpublished results of Professor Russell and Miss Moore.

[3] Meggers, *Astrophysical Journal*, **60**, 60, 1924; Laporte, *Proceedings Nat. Acad. of Sciences*, **12**, 496, 1926.

respectively; while the sixth indicates the behavior of the lines in an arc carrying over 1000 amp., as observed by King.[1] Here *S* means that even under this extreme excitation the line remains sharp; u_4 indicates great widening toward the side of longer wave-length, without reversal; ru_4 means partially reversed, with great dissymmetry, the long-wave side being stronger; w_2 means small widening without dissymmetry. As King's data for iron do not at present extend beyond λ 8400, only two members of the D–H multiplet are referred to in the sixth column.

In examining this comparison it should be remembered that the arc used by Meggers and Kiess was operated at atmospheric pressure with a current of 6 amp. and an arc length of 6 mm. The light was partially integrated by the method of projection. Under such conditions the wave-lengths of all sensitive lines exhibit a large amount of pole effect,[2] causing displacements from their normal positions amounting to several hundredths of an angstrom, toward the red for groups c_5 and *d*, toward the violet for group *e*. No lines belonging to group *e* occur in Table V. This group has not yet been definitely recognized in the infra-red spectrum of iron, and it may here be ignored.

The evidence of low pressure in the solar atmosphere may now be considered conclusive. Saha,[3] St. John,[4] Russell,[5] Stewart,[6] and St. John and Babcock[7] have shown, both from theoretical considerations and from several kinds of observational data, that the pressure in the sun has a negligible influence on the positions of Fraunhofer lines.

Two causes evidently operate to make the wave-lengths of the arc lines in Table V appear too great with respect to their values in the sun, namely, the higher pressure existing in the arc and the pole effect. These causes will be effective to varying degrees with different types of lines, but in general they will rise and fall together.

[1] *Mt. Wilson Contr.*, No. 298; *Astrophysical Journal*, **62**, 299, 1925.

[2] *Mt. Wilson Contr.*, No. 106; *Astrophysical Journal*, **42**, 1, 1915.

[3] *Philosophical Magazine*, **40**, 809, 1920.

[4] *Contributions of the Jefferson Physical Laboratory*, **15**, 1921.

[5] *Mt. Wilson Contr.*, No. 225; *Astrophysical Journal*, **55**, 134, 1922.

[6] *Physical Review*, **22**, 324, 1923.

[7] *Mt. Wilson Contr.*, No. 278; *Astrophysical Journal*, **60**, 399, 1924.

The correlation shown between the last four columns of Table V is emphasized by the rearrangement of the data in Table VI, where mean values of the differences sun *minus* arc and the excitation

TABLE V

COMPARISON OF SOLAR AND ARC WAVE-LENGTHS FROM INTERFEROMETER MEASUREMENTS

λ I.A.		SUN *minus* ARC	E.P. VOLTS	MULTIPLET	HIGH-CURRENT ARC
Table II	Arc; Meggers and Kiess				
6916.677	.709	−0.032 A	4.136	J–f	u_4
6945.210	.211	− .001	.....	.....	*S*
6978.861	.857	+ .004	.....	.....	*S*
7022.958	.976	− .018	4.173	J–U	u_4
7068.423	.418	+ .005	.....	.....	*S*
7090.390	.410	− .020	4.212	J–U	u_4
7130.925	.946	− .021	4.199	J–U	u_4
7207.396	.422	− .026	4.136	J–U	u_4
7389.391*	.423	− .032	4.283	K–U	u_4
7411.158	.184	− .026	4.265	K–U	u_4
7418.674†	.676	− .002	.....	.....	*S*
7445.755	.778	− .023	4.238	K–U	u_4
7491.652	.678	− .026	4.283	K–U	u_4
7495.076	.092	− .016	4.202	K–U	u_4
7507.276	.300	− .024	4.396	L–f	u_4
7511.030	.047	− .017	4.160	K–U	ru_4
7531.152	.178	− .026	4.353	L–f	u_4
7568.906	.931	− .025	4.265	K–U	u_4
7583.796	.801	− .005	.....	.....	*S*
7586.025	.050	− .025	4.294	L–f	u_4
7661.196	.230	− .034	4.238	K–U	u_4
7664.297	.306	− .009	.....	.....	*S*
7710.367	.397	− .030	4.202	K–U	u_4
7748.284	.282	+ .002	.....	.....	*S*
7780.567	.594	− .027	4.454	M–f	u_4
7832.207	.233	− .026	4.416	M–f	u_4
7937.149	.172	− .023	4.294	L–U	u_4
7945.857	.882	− .025	4.368	M–f	u_4
7998.952	.980	− .028	4.353	L–U	u_4
8046.056	.084	− .028	4.396	L–U	u_4
8085.175	.207	− .032	4.426	L–U	u_4
8220.393	.413	− .020	4.302	L–U	u_4
8327.060	.069	− .009	2.188	D–H	w_2
8331.927	.956	− .029	4.368	M–U	u_4
8387.783	.787	− .004	2.167	D–H	w_2
8468.420	.422	− .002	2.213	D–H	.....
8514.081	.088	− .007	2.188	D–H	.....
8688.642	.641	+ .001	2.167	D–H	.....
8824.233	.238	−0.005	2.188	D–H	.....

* Solar λ poor.

† Only one solar plate.

potentials are shown. It is clear that these arc wave-lengths exhibit a combined pole effect and pressure displacement, which increases with the excitation potential in a manner analogous to what has been found in the visible region, and that the lines in Table V which are not yet assigned to multiplets must be characterized by an excitation potential not much in excess of 2 volts.

On the basis of experience in using such an arc as that described by Meggers and Kiess, from measurements of the pole effect made by St. John and Babcock,[1] and from unpublished determinations of the pressure shift under conditions practically free from pole effect, an estimate may be made of the amounts which should be subtracted from the iron-arc wave-lengths of Meggers and Kiess to reduce them to what they would have been if a vacuum arc had been used. For iron lines arising from combinations of J, K, L, and M terms with a U term or an *f* term, the data indicate a deduction of about 0.04 A, while for the D–H multiplet about 0.02 A would suffice. The application of these changes to the arc wave-lengths would result in a consistent series of sun *minus* arc differences averaging +0.015 A.

The gravitational displacement predicted by Einstein averages +0.017 A in the region discussed here, and it may reasonably be expected to appear when vacuum-arc measurements of high accuracy become available.

The sun *minus* arc differences in Table V, when grouped according to solar intensity and behavior in high-current arc, show that the more intense solar lines are slightly displaced toward longer wave-lengths as compared to weaker lines of the same multiplets. The data are too meager to justify any conclusion, but it is interesting to note that such effects are well established in the region of shorter wave-lengths, and have been discussed at length by St. John.[2]

Table V also indicates that neither the arc wave-lengths of Meggers and Kiess nor the new solar wave-lengths now presented are affected by serious accidental errors. Were such errors present with random distribution, the chances are that at least three would

[1] *Loc. cit.*

[2] *Proceedings of the National Academy of Sciences*, 12, 65, 1926.

appear in Table V, whereas none are found to exceed 0.006 A. It is also very unlikely that systematic errors independent of the source of light exceeding a few thousandths of an angstrom occur in either list of lines. Inasmuch as the range of wave-length is 1800 A, the existence of such errors would obscure the relation between excitation potential and difference between solar and arc wave-length shown in Table VI.

So much has been said about the differences in structure and behavior of various types of lines when studied in artificial sources

TABLE VI

UNCORRECTED SUN—ARC DISPLACEMENT COMPARED WITH EXCITATION POTENTIAL

Multiplet	No. Lines	Mean E.P. Volts	Mean Difference Sun *minus* Arc	High-Current Arc
D–H.....	6	2.185	−0.004 A	w_2
J–f.....	1	4.136	.032	u_4
J–U.....	4	4.180	.021	u_4
K–U.....	9	4.237	.026	u_4
L–f.....	3	4.348	.025	u_4
L–U.....	5	4.354	.026	u_4
M–U.....	1	4.368	.029	u_4
M–f.....	3	4.413	.026	u_4
?.....	7	?	.001	S

that it may be well to recall some related facts in regard to the solar spectrum. For example, Fabry and Buisson,[1] after describing the peculiarities of some iron-arc lines, go on to say:

> Dans le spectre solaire, ces différences d'aspect ne se manifestent aucunement. On n'aperçoit aucune dissymétrie dans l'absorption; les raies diffèrent uniquement par leur intensité, ou, ce qui revient au même, par leur largeur. Certaines raies qui, dans l'arc à la pression atmosphérique, sont nettement diffuses et se distinguent des autres au premier coup d'œil, ne présentent rien de particulier dans le spectre solaire. On peut citer, comme exemple frappant de ce fait, les raies 5410.92, 5415.22, 5424.09.

St. John and Ware also noted[2] that iron lines of groups *d* and *e* are as sharp in the solar spectrum as those of groups *a* and *b*.

It is interesting to note that the remarks of Fabry and Buisson

[1] *Astrophysical Journal*, **31**, 112, 1910.

[2] *Mt. Wilson Contr.*, No. 61; *Astrophysical Journal*, **36**, 235, 1912.

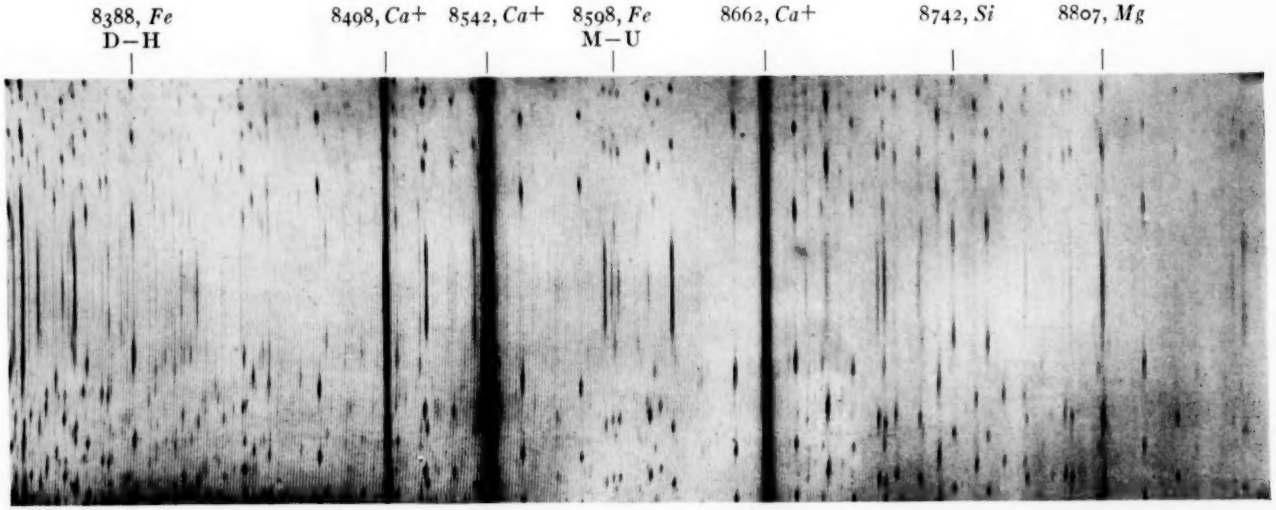
apply accurately to the infra-red region of the solar spectrum, since our photographs show that here, as well as in the visible region, lines, which in the arc are extremely diffuse and unsymmetrical, are symmetrical and sharp in the solar spectrum.

Plate III shows a small part of the spectrum in which solar lines predominate. This illustration is an enlargement of 1.5 times from a negative made with a 2.5-mm etalon having gold films. The original exposure was thirty-one minutes. A few lines are marked, among which may be found members of both the M–U and D–H multiplets. The photograph also illustrates the foregoing remarks on the appearance of the solar lines.

My cordial thanks are due to Miss Moore for access to unpublished data which she and Professor Russell are preparing, and to Mrs. Thome, née Keener, for assistance in measuring some of the grating plates of the α-band of oxygen.

MOUNT WILSON OBSERVATORY
December 1926

PLATE III



SPECTRUM OF INTEGRATED SUNLIGHT

Order of Interference at λ8600 is 6000

INTERSTELLAR CALCIUM[1]

By OTTO STRUVE

ABSTRACT

Intensities of detached calcium lines.—Estimates have been made for 321 stars of spectral type not later than B3. Some of these were from spectrograms in the collections of the Mount Wilson, Victoria, Lick, and Yerkes observatories; others from plates taken by me with the 60-inch reflector at Mount Wilson. *The mean intensity of detached lines increases* from 1.6 to 3.6 units between 1 and 7 mag. The *probable error* of a single estimate is 0.5 unit. One unit corresponds to a difference of about 0.1 mag. between the intensity of the continuous spectrum at λ 3933 and the center of the K line. The increase in intensity for the fainter stars is probably an *effect of distance*, the space around the sun out to 150 or 200 parsecs being unfavorable for the appearance of strong detached lines. The strongest lines occur at a distance of 500 or 600 parsecs, beyond which conditions are perhaps again less favorable for the production of strong lines. *Regional effects* seem to be the most important factor in defining the intensity of detached K. In Cepheus (36 stars) the mean intensity is more than 5 units, while in Orion (24 stars) it is only 2 units. *B3 stars have*, on the average, *weaker lines* than the earlier spectral subdivisions. Detached lines seem *not to occur in types later than B3*. The lines appear to be slightly *stronger* in a belt of 20° along *the plane of the Milky Way*.

The components of visual *double stars have identical intensities*, without respect to differences in brightness or spectral type. The spectroscopic binary *2 Lacertae*, type B3, *shows a detached calcium line* between two stellar components, at or near the time of passage through the node.

Calcium cloud in Cepheus.—The residual velocities from detached K lines of 36 stars in the Cepheus region are *systematically smaller* than those from the stellar lines, and effects of group motion may be present. The intensity of K in these stars is slightly smaller in regions where dark nebulae are present. It is estimated that the *distance* of the beginning of the *calcium cloud* is *250 parsecs*. The *dark nebula* is found, from star-counts, to be at a distance of about 350 parsecs. The region of strong calcium lines in Cepheus extends into portions of the Milky Way where the distribution of stars is normal, whence it is believed that *calcium clouds are transparent*.

INTRODUCTION

Although twenty-two years have elapsed since Hartmann discovered "stationary" calcium lines in the spectrum of the binary δ Orionis, our knowledge concerning the origin of these lines has advanced but little.[2] The most important observational investigation made in recent years is that of J. S. Plaskett.[3] From this we now know that the peculiar lines of calcium and sodium are not confined to spectroscopic binaries alone, but occur in nearly all stars of spec-

[1] *Contributions from the Mount Wilson Observatory*, No. 331.

[2] For a more detailed summary of earlier work on detached calcium lines see my paper in *Popular Astronomy*, **33**, 639, 1925; **34**, 1, 1926.

[3] *Publications of the Dominion Astrophysical Observatory, Victoria*, **2**, 335, 1924; *Monthly Notices of the Royal Astronomical Society*, **84**, 80, 1924.

tral type not later than B3. Since the calcium lines in stars of constant velocity have exactly the same properties as the so-called "stationary lines" in spectroscopic binaries, I am following a suggestion by P. W. Merrill[1] in using the word "detached" throughout this paper. This term includes all lines that behave differently from ordinary stellar lines with respect to Doppler shift, intensity, width, and general appearance.

Plaskett has shown that the radial velocities derived from detached lines do not agree with those from ordinary lines, and that the difference is frequently so large that it cannot be explained by abnormalities in wave-length or in the structure of stellar absorption lines. Furthermore, the velocities from the detached lines have a tendency to agree very closely with the radial component of the solar motion, indicating that, referred to our stellar system, the peculiar velocities of the gases responsible for the appearance of these lines are small.

In explaining the origin of detached lines Plaskett modified the original hypothesis of Hartmann. He suggested that the detached lines are produced by absorption in a "widely distributed tenuous cloud of matter," enveloping the stars so that its calcium atoms will be ionized in the neighborhood of the hottest stars. This would account for the occurrence of the detached lines in spectral types O and B only.

For details of other investigations concerning the detached calcium lines the reader is referred to the original papers by R. K. Young,[2] G. Strömberg,[3] H. Kienle,[4] H. Vogt,[5] H. Ludendorff,[6] J. Woltjer,[7] F. Henroteau,[8] M. N. Saha,[9] B. P. Gerasimovič,[10] and

[1] *Publications of the Astronomical Society of the Pacific*, **38**, 211, 1926.

[2] *Publications of the Dominion Astrophysical Observatory, Victoria*, **1**, 219, 1920; *Journal of the Royal Astronomical Society of Canada*, **19**, 46, 1925.

[3] *Mt. Wilson Contr.*, No. 293, p. 10; *Astrophysical Journal*, **61**, 372, 1925.

[4] *Probleme der Astronomie; Festschrift für H. v. Seeliger*, p. 38, 1924; *Monthly Notices of the Royal Astronomical Society*, **84**, 583, 1924.

[5] *Astronomische Nachrichten*, **224**, 16, 1925. [6] *Ibid.*, **212**, 3, 1920.

[7] *Bulletin of the Astronomical Institutes of the Netherlands*, **2**, 195, 1925.

[8] *Journal of the Royal Astronomical Society of Canada*, **14**, 234, 1920; **15**, 62, 109, 1921.

[9] *Nature*, **110**, 488, 1921. [10] *Ibid.*, **113**, 458, 1924.

others. My previous work, of which the present paper is a continuation, will be found in several short articles.[1] Of particular importance is A. S. Eddington's recent discussion on "Diffuse Matter in Interstellar Space."[2] From theoretical considerations Eddington concludes that it is impossible to assume that the detached-line absorption, although occurring in an interstellar cloud, is controlled by the hot stars, stellar radiation being required to alter the constitution of the calcium and to produce the peculiar lines in stellar spectra. From certain assumptions he finds that "proximity to a very hot star would decrease the amount of Ca+ by causing more double ionization." Eddington suggests that absorption occurs evenly all along the path of the light, and that diffuse matter of calcium and other elements is present everywhere in sufficient quantity to produce appreciable monochromatic absorption, but in insufficient quantity to affect to any measurable amount the brightnesses or the colors of the stars.

The present contribution gives additional observational material concerning detached calcium lines and an interpretation of this material from the point of view of the two hypotheses—that of Eddington and that of Plaskett.

Preliminary work on spectrograms taken at the Yerkes Observatory showed that certain deductions could be made from the intensities of the detached lines. If the detached lines do not originate in the atmospheres of the stars, their intensities must be functions, not only of stellar temperature, but also of the properties of the clouds, and interesting revelations may be expected from a study of such intensities.

Plaskett's list of radial velocities determined from detached lines includes 40 stars. Because of the excellence of the Victoria equipment and the special care taken by Dr. Plaskett, these velocities are undoubtedly the best available at present. About 70 calcium velocities were made accessible by the publication of the velocities of 368 helium stars observed at the Yerkes Observatory.[3] It seemed

[1] *Popular Astronomy*, **33**, 639, 1925; **34**, 1, 158, 1926; *Astronomische Nachrichten* **227**, 377, 1926; *Publications of the Astronomical Society of the Pacific*, **38**, 211, 1926.

[2] *Proceedings of the Royal Society of London*, A, **111**, 424, 1926.

[3] *Astrophysical Journal*, **64**, 1, 1926.

desirable, however, to obtain more radial velocities, in order to strengthen Plaskett's results and to permit the investigation of systematic motions of separate calcium clouds.

The material on line intensities, on which the first part of this paper is based, was obtained by me during the summer of 1926, at the Mount Wilson, Victoria, and Lick Observatories. Through the courtesy of the directors, Dr. W. S. Adams, Dr. J. S. Plaskett, and Dr. R. G. Aitken, I was permitted to look over a large number of spectrograms of early-type stars and to make estimates of the intensities of the calcium line K. Although not complete for stars of every given apparent magnitude, these estimates are ample for an independent discussion, including the determination of systematic and probable errors.

The second part of the investigation—that concerning the radial velocities and intensities from the detached calcium lines in a limited region of the sky—was made during a stay of three months at the Mount Wilson Observatory. Most of the necessary spectrograms were obtained with the 60-inch reflector. Two plates were taken by Mr. A. H. Joy with the 100-inch telescope, and several earlier plates by various observers at Mount Wilson were also utilized. For the brighter stars, I used the material available at the Yerkes Observatory, which was published in part in the paper on 368 helium stars. Several additional plates were taken by Professor S. B. Barrett and Mr. C. T. Elvey with the Bruce spectrograph attached to the 40-inch refractor.

Each of the three spectrographs was equipped with one prism. The cameras are of different focal lengths, and the linear dispersions are not the same. The Yerkes plates have the largest scale, about 30 A to the millimeter at λ 4500. The Mount Wilson plates taken with the 60-inch telescope are on a slightly smaller scale, about 45 A to the millimeter, while the scale of the spectrograph attached to the 100-inch is only about 80 A to the millimeter. The quality of the plates is nearly uniform in all three cases.

The special region selected for study was that in Cepheus, in which I had previously suspected the existence of abnormally strong detached lines. Furthermore this region is interesting because of the comparatively large positive values of the color-excess for a con-

siderable number of stars.[1] The stars observed were selected from the *Draper Catalogue* between α 21^h0^m and 22^h20^m and δ $+50°0'$ and $+70°0'$. An attempt was made to observe the 36 stars within the foregoing limits for which this *Catalogue* gives the spectral type as not later than B3. Two of these had to be excluded because of faintness. In their place I included two other stars, situated somewhat farther to the south. While selecting these it was noticed that the number of objects of spectral type earlier than B5 situated in the dense galactic star cloud between α 21^h50^m and 22^h15^m and δ $+40°$ and $50°$ is unexpectedly small—only 3 in an area of 43 square degrees, while in an approximately equal area, adjoining on the north, the number is 22. The 36 stars of the final observing program are divided nearly equally between areas where the stellar distribution seems to be normal and where there are striking obscuring nebulae. Several stars are in the large bright nebula in Cepheus, around α 21^h35^m, δ $+57°$, which was discovered by E. E. Barnard and frequently photographed both by him and by Dr. Max Wolf, of Heidelberg. Because of this distribution it was possible to investigate the relation between calcium clouds and obscuring or bright galactic nebulae.

I. DISCUSSION OF THE INTENSITIES

Material.—In estimating the intensity of the K line of calcium I have followed the method previously used for the Yerkes spectrograms.[2] The plate was put under a microscope or a low-power eyepiece, and the intensity of the center of the K line with respect to the adjoining portion of the continuous spectrum was estimated on an arbitrary scale. If no line could be seen, the intensity was called "0." If a line was suspected but not definitely seen, it was called "1." A very faint line, the reality of which seemed certain, was denoted by "2." A faint line seen without difficulty was indicated by "3." Fairly strong lines were indicated by "4" and "5." A line corresponding in intensity to the K line in Vega was denoted by "10." In the majority of cases the detached lines are fainter than this value, but for a few stars they are somewhat stronger than 10.

[1] *Astronomische Nachrichten*, **227**, 377, 1926.

[2] *Popular Astronomy*, **33**, 651, 1925; **34**, 4, 1926.

Precision of the intensity estimates.—The intensities of the detached K line had previously been estimated for 152 stars observed at Yerkes. To determine the accuracy of the estimates I determined the intensities of the K line for a large number of stars on spectrograms available at the Victoria, Lick, and Mount Wilson Observatories. As a result, determinations of intensity from more than one observatory are available for 94 stars. Since the various estimates were made independently, at different observatories, and on plates obtained with different instruments, they afford material for deriving systematic and probable errors, and thus provide a test of the accuracy of the whole method. My own Mount Wilson observations were treated in this comparison as an independent series of estimates. The residuals from the mean intensity for each star lead to the systematic and probable errors shown in Table I.

TABLE I

SYSTEMATIC AND PROBABLE ERRORS OF INTENSITY ESTIMATES

	Observatory				
	Yerkes	Victoria	Lick	Mt. Wilson	Mt. Wilson, Struve
Number of stars	67	63	7	51	20
Systematic error	+ 0.22	− 0.02	− 0.17	− 0.03	− 0.12
Probable error of one estimate	± 0.55	± 0.51	± 0.25	± 0.50	± 0.61

The systematic errors are in all cases very small, and can safely be neglected. Since in the following discussion all groups of stars include estimates from different observatories, it is obvious that systematic errors of more than 0.1 unit will not occur, which is about the limit of accuracy to be expected. The probable errors are also small, ±0.5 unit on the average. This means that, in the majority of cases, a single estimate is accurate within 1 unit. The small values of both the systematic and probable errors are reassuring, and give confidence in the results obtained from the estimates.

Effect of under-exposure.—In my earlier investigation,[1] based wholly on spectrograms obtained at the Yerkes Observatory, the limiting magnitude was 6.0. It was found[1] that the intensity of the

[1] *Publications of the Astronomical Society of the Pacific*, **38**, 220, 1926.

K line increased for the fainter stars, and it was inferred that under-exposure did not vitiate the results. This conclusion is now confirmed by a much larger amount of material. At Victoria and Mount Wilson stars of apparent magnitude 6.0 can be photographed in a few minutes, and the limiting magnitude lies close to 9.0. The new material, therefore, extends the list to much fainter stars; nevertheless, the general run of average intensity with apparent magnitude remains essentially the same as for the Yerkes spectro-

TABLE II

EFFECT OF UNDER-EXPOSURE

Star	Plate	Limiting λ Cont. Sp.	Intensity of K	Remarks
Boss 5642.....	γ 12224	λ 3920	3	
	γ 12110	λ 3920	4	
	γ 12013	λ 3889	4	
	γ 12283	λ 3889	6	
	γ 12205	λ 3889	5	
Boss 5535.....	γ 6205	λ 3957	.....	Invisible
	γ 5932	λ 3900	4	
	γ 3748	λ 3841	4	
H.D. 209339.....	γ 1924	λ 3928	4	
	γ 2566	λ 3860	4	
B.D.+57°2309....	C 2792	λ 3889	9	
	C 2325	λ 3879	10	
	C 2435	λ 3860	10	
	C 2429	λ 3860	8	
χ^2 Orionis.....	C 2641	λ 3879	11	
	C 899	λ 3860	8	
	γ 10765	λ 3841	8	
	γ 12404	λ 3841	10	

grams alone, thus indicating that the earlier data were not affected by under-exposure.

To obtain an independent test of the effects of under-exposure, I selected from the Mount Wilson collection spectrograms of several stars for which weak and strong plates were available and such that detached lines of both strong and average intensity were represented. On these plates I estimated the intensity of the detached K line and also noted the approximate wave-length in the violet to which the continuous spectrum extended. The results are shown in Table II, in which the plates are arranged in the order of increasing density.

The first star shows a slightly greater intensity, of the order of

1.5 units, for the stronger plates; but for the others the effect is completely absent. We conclude that if a plate is strong enough to show the continuous spectrum to about λ 3900, the estimated intensity may be regarded as reliable; but on weak plates extending only to λ 3920 there is some danger of making too low an estimate.

In most of my estimates, I made no record of the limiting wavelength. It is therefore not possible to check the number of plates on which the continuous spectrum extends only to λ 3920. Stars of apparent magnitude 7 or brighter can safely be regarded as being free from effects of under-exposure. For the fainter stars caution must be exercised in the interpretation of the results. For the brightest stars estimates were made only on plates of normal density, and effects of over-exposure need not be considered.

Calibration of intensity scale.—The spectra of a few bright stars were photographed on the same plate with varying exposure times, and the photographic density of the center of the K line, obtained with a long exposure, was matched up with the density of the continuous spectrum, obtained from a short exposure. The ratios of exposure times were then converted into intensities by means of Schwarzschild's formula. The method was first applied to Arcturus and the sun, with the result that the strongest lines appeared to be about 2 mag. fainter than the continuous spectrum. For several A-type stars the values for the magnesium line at λ 4481 ranged from 0.3 to 1.8 mag. These results are in general agreement with those of Bottlinger,[1] who found that in stars such as α Cygni and Sirius λ 4481 had an intensity 1.0–1.2 mag. below that of the background.

The same method was later applied to the calcium line K in several stars,[2] with the following results:

Star	Intensity of *Ca*K on Arbitrary Scale	Mag. Diff. Line and Cont. Spectrum
α Lyrae	10	1.8
γ Orionis	4	0.8
β Tauri	2	0.6

[1] *Astronomische Nachrichten*, **195**, 119, 1913.

[2] *Popular Astronomy*, **33**, 652, 1925.

These results are very uncertain because of the inaccuracy of the method used. In a recent paper by Cecilia H. Payne and Harlow Shapley,[1] the intensity of the K line in Vega is given as 0.23 mag. This value was obtained from microphotometer tracings and, as far as the photometric method is concerned, is certainly reliable. Even a casual glance at our plates, however, shows that the difference between the continuous spectrum and the center of the line is much greater than the value obtained at Harvard. The problem may be compared to that of estimating stellar magnitudes on direct photographs, where under the best conditions a difference in photographic density corresponding to 0.1 mag. can be detected. The faintest visible spectral lines should therefore correspond to a similar difference in density. If the plates are over- or under-exposed or influenced by the Eberhard effect, or if the width of monochromatic absorption is small in comparison to the theoretical line-width of the spectrograph, then the limiting difference in intensity for which a line is detectable will be rather more than 0.1 mag. For the particular line λ 3933, it is also necessary to take into consideration the relation between contrast and wave-length. F. E. Ross has shown[2] that under ordinary conditions and for simple blue-sensitive plates the contrast factor gamma decreases for the shorter wave-lengths. From his experiments I find that for λ 3900 gamma = 0.5, while for λ 4800, where the continuous spectrum is strongest, gamma = 1.2. Such a large difference in contrast tends to increase the limiting difference in intensity detectable with the eye. It would probably be more nearly correct to assume that the faintest K line discernible with certainty has an intensity about 0.2 mag. lower than the background of continuous spectrum.

If in the case of Vega we imagine that we are dealing, not with spectra, but with star-images, one of the density of the continuous spectrum at λ 3930, the other of the density of the center of the K line, we should estimate the difference in density to be of the order of 1 or 2 mag. This value roughly confirms that obtained from scale plates.

[1] *Proceedings of the American Academy of Arts and Sciences*, **61**, 459, 1926; *Harvard Reprint*, No. 28.

[2] *Physics of the Developed Photographic Image*, p. 74, 1924.

In order to determine entirely independent values of the intensity, I obtained tracings from some of the plates with the registering thermoelectric microphotometer of the Mount Wilson Observatory. Photographed upon the plates was a photometric scale by means of which it was possible to read off the intensities corresponding to various densities on the plate. Scale and spectrum were given the same treatment, except that the wedge was exposed to the light of an ordinary electric lamp, of effective wave-length near λ 4800. Since the K line has a wave-length of 3933 A, it is necessary to introduce corrections for change of contrast with change of wave-length. According to Ross, the value of gamma at K, as previously stated, is only about one-half of that which would apply to the wedge. As a check on this effect of contrast, I used a number of exposures of the wedge made with the same electric lamp and battery as were used for the spectrograms. These exposures, for which I am indebted to Dr. E. Pettit, were made, some without filter and others with a combination of Wood's U.V. filter with Corning heat-absorbing glass 124J, which has a maximum transmission at λ 3750. A comparison of the plates shows clearly less contrast for the exposures made through the screen, but the corrections are somewhat smaller than those derived from Ross's values of gamma. In view of this slight discordance, I have adopted averages from the corrections of Pettit and of Ross.

Intensities were determined with the microphotometer for eleven plates. Grouping these according to intensity and smoothing the results, I obtained the following approximate calibration for my estimates:

Estimate.....	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Mag. diff.....	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3

These values are somewhat smaller than those obtained from direct comparisons, but their order of magnitude is about the same. The relation between my arbitrary estimates and the magnitude difference is linear. One unit in the arbitrary scale corresponds to about 0.1 mag.

Regional effects.—Figure 1 represents the intensities of detached K lines, plotted on Aitoff's equal-area projection of the sphere.

Galactic co-ordinates as defined in *Harvard Annals*, **56**, were used. The average intensity of all individual estimates for every star was plotted according to its position in the sky. The total number of

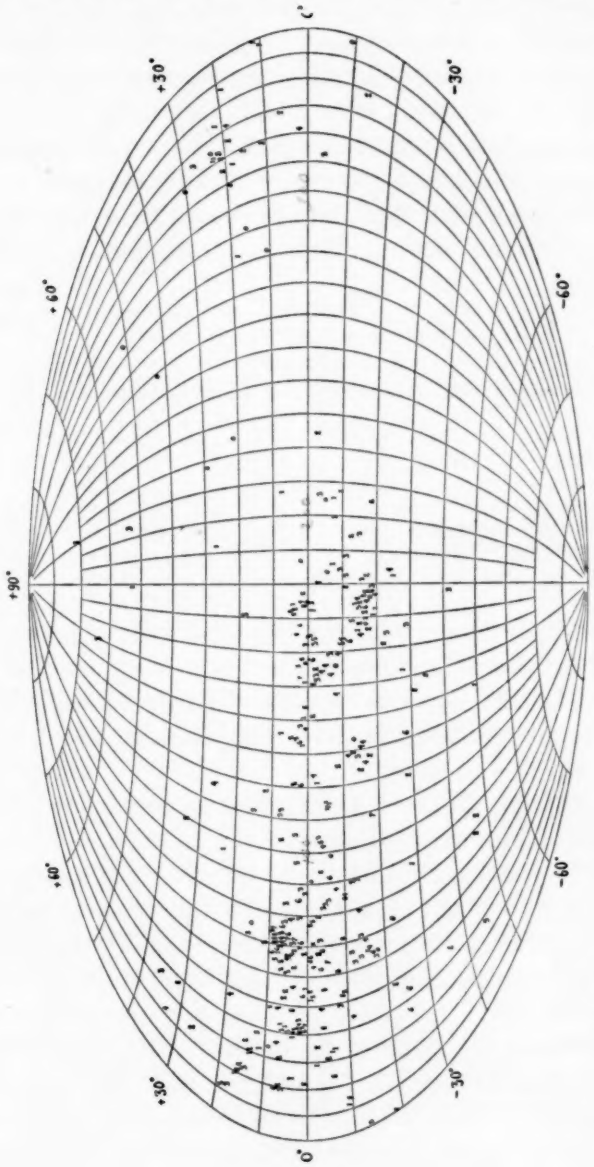


FIG. 1.—Distribution according to galactic co-ordinates of the intensities of the detached calcium line K in 321 stars of spectral types O–B3. Absence of K is denoted by *O*; the strongest lines, corresponding to those of Vega, are called 10 = *x*.

stars is 321. Of these 155 were photographed at Yerkes, 131 at Victoria, 107 at Mount Wilson by various observers, 8 at the Lick Observatory, and 37 estimates were derived from my own plates taken at Mount Wilson with the 60-inch reflector.

The distribution of the stars along the Milky Way is not uniform. In a portion of the southern sky the estimates are completely lacking, while they are especially numerous in longitudes 70° and 170°. The first region falls in the constellation of Cepheus, while the second lies in Orion, where B and O stars are especially frequent.

The intensities of detached lines in these two regions show an unmistakable regional effect. In Cepheus strong lines are unusually

TABLE III

INTENSITIES OF DETACHED LINES IN CEPHEUS AND IN ORION

	Cepheus	Orion
Number of stars	36	24
Mean intensity	5.1	2.2
Probable error of mean	± 0.15	± 0.06
Standard deviation	± 1.9	± 1.0
Range in intensity	0–15	0–6

numerous, while in Orion faint lines are the more abundant. For two circular areas of 8° radius, centered at galactic longitude 71°, latitude +3° for the Cepheus region and longitude 174°, latitude −14° for Orion, the intensities have the characteristics shown in Table III.

The outstanding difference in mean intensity cannot be attributed to chance. Since the mean spectral type is the same for the two groups, B1, the effect cannot be due to differences in spectral type. The average apparent magnitude is 6.4 for the Cepheus region and 4.2 for Orion. The suspicion might therefore arise that the effect is one of distance, especially since such an effect actually exists for the mean of all stars. If, however, we use only the brightest stars in the Cepheus region, some 20 in number, the average intensity is even larger, which proves that in this case the effect is not due to greater distance. We are thus led to the conclusion that a certain portion of space—in the constellation Cepheus—favors the produc-

tion of strong detached calcium lines, while another portion of space —in Orion—is more favorable for the production of weak lines.

Intensities of detached calcium lines as a function of distance.—Eddington was the first to suggest that the intensity of a detached line may be a function of distance.[1] Guided by this suggestion, I have attempted to find whether the estimates show such a relationship.

The number and the relative precision of trigonometric parallaxes for B and O stars are insufficient for an investigation of this kind. It was therefore necessary to use other criteria for distance,

TABLE IV

INTENSITY OF DETACHED K AS A FUNCTION OF APPARENT MAGNITUDE

Apparent Magnitude	Number of Stars	Mean Intensity of K
1.0–1.9	7	1.6
2.0–2.9	17	1.7
3.0–3.9	22	2.5
4.0–4.9	78	2.9
5.0–5.9	89	3.1
6.0–6.9	64	3.6
7.0–7.9	34	3.6
8.0–8.9	7	2.1
9.0–9.9	3	2.7
	321	3.03

such as apparent magnitude. Accordingly, I have grouped all 321 stars according to brightness, as shown in Table IV.

The mean intensity for all 321 stars is 3.03. The data, plotted in Figure 2, show a definite increase in intensity between magnitudes 1 and 7. For fainter stars the intensities are slightly smaller. In order to find whether the relationship is a consequence of systematic errors, I made separate tabulations for the different sets of plates; but the result remained essentially the same. Regional effects and those of spectral type were also looked into, without finding any evidence that would tend to discredit the results. Accordingly, we seem to be justified in assuming that the increase in intensity from magnitudes 1 to 7 is an essential property of detached calcium lines. The decline in intensity for magnitudes 8 and 9, although indicated by

[1] *Proceedings of the Royal Society of London*, A, 111, 424, 1926.

the figures in Table IV and supported by certain other evidence, should not be regarded as definitely established. It is based on a comparatively small number of stars, and may be influenced by regional effects. As we have seen, it is also possible that effects of under-exposure become sensible for stars fainter than magnitude 7.

At the suggestion of P. W. Merrill I have attempted to correlate intensity directly with distance. It is obvious that mixing stars of different absolute magnitudes increases the dispersion. To avoid

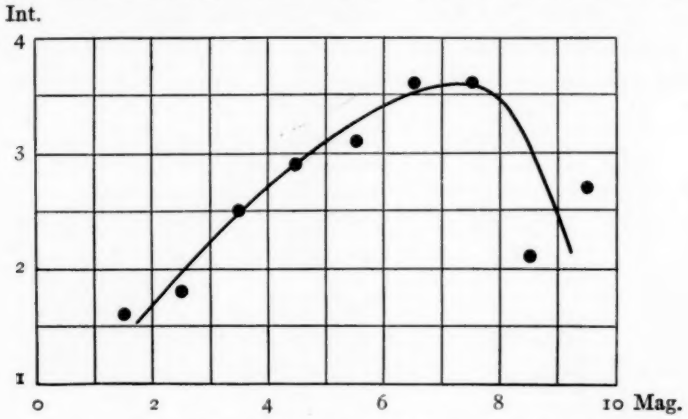


FIG. 2.—Intensity of the detached K line as function of apparent magnitude

this I computed the distances of the stars, in parsecs, from the formula

$$\log D = \frac{m-M}{5} + 1 .$$

For the O Stars I used $M = -4.0$, which is the value found for them by J. S. Plaskett.[1] For the B stars I adopted the means of the values given by Adams and Joy:[2] Bo, -3.1; B1, -2.5; B2, -1.8; B3, -1.2. The spectral types used were those given in the *Draper Catalogue*, except in a few cases where Mount Wilson determinations or my own estimates seemed to be more accurate. The average intensities, grouped according to distance, are shown in Table V.

The relation between intensity and distance is plain. The total range in intensity here is 2.5 units, while in Table IV it is 2.0 units.

[1] *Publications of the Dominion Astrophysical Observatory, Victoria*, **2**, 328, 1924.

[2] *Astrophysical Journal*, **57**, 294, 1923 (Table I); *Mt. Wilson Contr.*, No. 262.

In an earlier publication[1] I have suggested that the average intensity of detached lines may depend on spectral type, for the earlier spectral subdivisions exhibit somewhat stronger lines than

TABLE V

INTENSITY OF DETACHED K AS A FUNCTION OF DISTANCE

Distance in Parsecs	No. of Stars	Intensity of K
0–100	22	2.1
100–200	101	2.2
200–300	62	3.1
300–400	47	3.3
400–600	30	4.2
600–800	26	4.6
800–3900	33	3.9

the later ones. It appeared desirable, therefore, to investigate the run of intensities with apparent magnitude separately for each spectral subdivision. The O-type stars were so few in number that they were combined into one group. Subdivisions Bo, B1, B2, and B3 were examined separately. Table VI gives the numerical results,

TABLE VI

INTENSITY OF K FOR DIFFERENT SPECTRAL TYPES

App. Mag.	O		Bo		B1		B2		B3	
	No.	Av. Int.	No.	Av. Int.	No.	Av. Int.	No.	Av. Int.	No.	Av. Int.
1.0–1.9	.....	.....	2	2.2	2	1.5	2	1.8	1	0.3
2.0–2.9	2	1.8	6	1.4	4	2.2	2	1.5	3	2.0
3.0–3.9	1	5.5	2	3.6	3	1.0	6	2.4	10	2.6
4.0–4.9	3	5.3	6	3.6	8	3.4	11	4.3	50	2.3
5.0–5.9	8	4.7	9	5.1	4	5.4	10	4.3	58	2.2
6.0–6.9	6	4.2	8	4.3	2	4.2	8	4.5	39	3.1
7.0–7.9	4	3.4	5	4.1	3	3.5	9	4.2	14	3.3
8.0–8.9	1	1.0	4	2.2	1	3.0	1	15.0	.....	.....
9.0–9.9	1	3.0	1	2.0	.....	.....	.....	.....	1	3.0

and Figure 3, a graphical representation of intensity as a function of apparent magnitude.

The curves in Figure 3 are based on very few stars, and it is

[1] *Popular Astronomy*, **34**, 7, 1926.

therefore necessary to be cautious in their interpretation. In all five curves, however, the lowest intensities have a tendency to occur among the brightest apparent magnitudes. In all cases a maximum appears somewhere in the middle, followed by a small decline for the

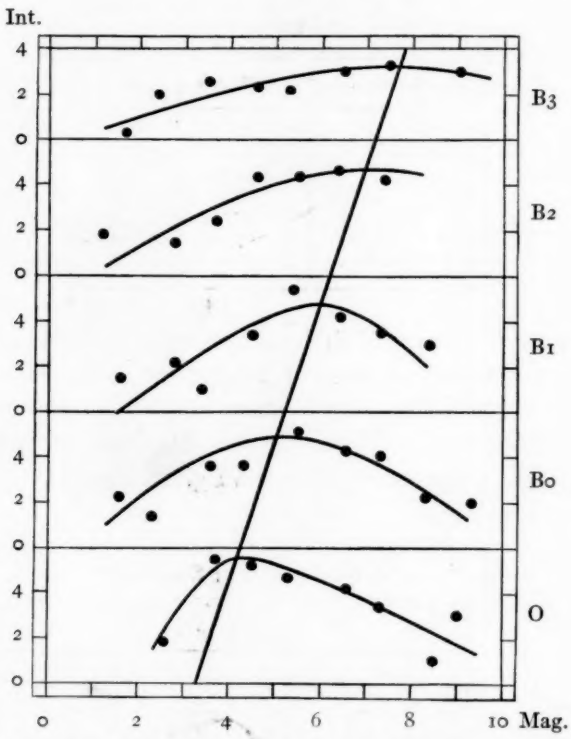


FIG. 3.—Intensity of detached K line as function of apparent magnitude, for separate spectral types. One star was omitted in type B2. The inclined straight line joins the maxima of the curves.

faintest stars. A progression in the maxima of the five curves from about magnitude 4 for type O to magnitude 7 for B3 seems also to be indicated. The inclined line in Figure 3 illustrates this progression. It is remarkable that this change in the position of maximum intensity corresponds almost exactly to the change in absolute magnitude. Indeed, if we read from the curves the points of maximum intensity and subtract the absolute magnitudes, we obtain:

Spectral Type	m − M
O	4.2+4.0=8.2
Bo	5.0+3.1=8.1
B1	6.0+2.5=8.5
B2	6.7+1.8=8.5
B3	7.5+1.2=8.7
Mean	8.4

These values would indicate that for a star of absolute magnitude 0.0, maximum intensity occurs at apparent magnitude 8.4, which corresponds, roughly, to a distance of 500 parsecs. This result is in fair agreement with the general run of the intensities for all stars. It means that the detached calcium lines are very faint in the neighborhood of the sun, that they increase in intensity for regions farther away from us, and that the strongest lines are favored by a spherical shell at a distance of about 500 parsecs from the sun. Beyond this distance conditions may be less favorable for the production of strong detached lines. It is necessary, at this point, again to call attention to the small number of stars fainter than the seventh magnitude. It is possible, therefore, that the decline in intensity for distances greater than 500 parsecs is not real.

Nevertheless, it is interesting to note that the distance of 500 parsecs, where our figures indicate maximum intensity for the detached K line, corresponds closely to the dimensions of the local cluster of B stars, as outlined by Charlier and later by Shapley.[1] One feels tempted, therefore, to suggest that the regions most favorable for the production of strong detached lines of calcium lie near the outer boundaries of the local cluster of helium stars. The results of E. S. King[2] also lead to the assumption of an absorbing medium in the local cluster which produces reddening of the more distant stars. Since strong detached calcium lines seem frequently to be associated with positive color-excess, it seems possible that King's absorbing medium and the local cloud of calcium are identical.

[1] *Proceedings of the American Academy of Arts and Sciences*, **59**, 22, 1924; *Harvard Reprint*, No. 6. However, Professor B. Gerasimovič informs me that he has recently obtained for the size of the local system a value twice as large.

[2] *Popular Astronomy*, **34**, 557, 1926.

The progression of the maxima in Figure 3 seems to support the decline in intensity for distances greater than about 500 parsecs; but, in view of the possibility that effects of underexposure become appreciable for faint stars, and also because of the small number of stars used, this result should be regarded as tentative. The gradual increase in mean intensity of detached K for distances up to 500 parsecs may, however, be regarded as certain.

O-type stars.—The results concerning the progression of the maxima in Figure 3 are based in part on the very asymmetric curve for O-type stars. It is for this same group of stars, however, that J. S. Plaskett found a large dispersion in absolute magnitude. More recent work by R. E. Wilson[1] tends to throw some doubt on the assumption that in O-type stars apparent magnitude is an indication of relative distance. His tables seem to indicate that the distance of all O stars is about the same, and that apparent magnitude is linearly correlated with luminosity. If this is correct, the curve for O stars cannot be interpreted as the result of varying distance, and the decline in intensity for the fainter stars, if real, must be attributed to a decline in luminosity.

Brightest stars.—In Table VII are listed all stars brighter than magnitude 3.0 for which the intensity of the detached K lines was estimated. Of these 24 stars only 3 have intensities that exceed 3.0—the mean for all 321 stars. The strongest line, 4.2, occurs in 44 ζ Persei. For 13 stars the intensities are between 0 and 2, which means that K was either absent entirely or was only suspected as a very faint line in the spectra of these stars.

Twenty-three of these stars are within 130 parsecs from the sun, and only one is at a distance as great as 250 parsecs. It seems, therefore, that the space around the sun out to 100 or 200 parsecs in all directions is not favorable for the production of strong detached lines of calcium.

Intensity and spectral type.—Grouping all the stars according to spectral type, but without respect to apparent magnitude, we find the mean intensities given in the third column of Table VIII.

With the exception of B2, the intensity declines smoothly toward the later types, agreeing well with preliminary results from

[1] *Astronomical Journal*, **36**, 1, 1924.

Yerkes plates.[1] Perhaps more representative are the maximum values from the five curves in Figure 3, which are given in the last column of Table VIII.

TABLE VII

LIST OF 24 BRIGHTEST STARS

Star	α 1900	δ 1900	Mag.	Sp.	Distance in Parsecs	Int. of K
88 γ Pegasi	$0^h\ 8^m.1$	+14° 38′	2.7	B2	80	2.0
27 γ Cassiop.	0 50.7	+60 11	2.0	Bop	100	0.0
44 ζ Persei	3 47.8	+31 35	2.9	B1	120	4.2
45 ε Persei	3 51.1	+39 43	2.7	B1	110	1.7
24 γ Orionis	5 19.8	+ 6 16	1.5	B2	45	3.5
34 δ Orionis	5 26.9	− 0 22	2.2	Bo	110	2.2
44 ι Orionis	5 30.5	− 5 59	2.9	Oe5	240	2.0
46 ε Orionis	5 31.1	− 1 16	1.5	Bo	83	3.0
123 ζ Tauri	5 31.7	+21 05	2.8	B3p	63	3.5
50 ζ Orionis br.	5 35.7	− 2 00	1.8	Bo	95	1.5
53 κ Orionis	5 43.0	− 9 42	2.0	Bo	100	2.0
2 β Can. Maj.	6 18.3	−17 54	1.8	B1	72	2.0
21 ε Can. Maj.	6 54.7	−28 50	1.4	B1	60	1.0
ζ Puppis	8 0.1	−39 43	2.3	Od	130	1.5
67 α Virginis	13 19.9	−10 38	1.0	B2	36	0.2
85 η Urs. Maj.	13 43.6	+49 49	1.7	B3	38	0.3
η Centauri	14 29.2	−41 43	2.5	B3p	55	0.5
6 π Scorpii	15 52.8	−25 50	2.8	B2	83	1.0
7 δ Scorpii	15 54.4	−22 20	2.3	Bo	120	1.0
8 β Scorpii	15 59.6	−19 32	2.7	B1	110	1.3
20 σ Scorpii	16 15.1	−25 21	2.9	B1	120	1.5
23 τ Scorpii	16 29.7	−28 01	2.7	Bo	140	2.0
13 ζ Ophiuchi	16 31.7	−10 22	2.5	Bo	130	1.3
34 σ Sagittarii	18 49.1	−26 25	2.0	B3	43	2.0

TABLE VIII

INTENSITY OF DETACHED K AS A FUNCTION OF SPECTRAL TYPE

Sp. Type	No. of Stars	Average Intensity	Maximum Intensity from Fig. 3
O	26	4.05	5.5
Bo	43	3.56	5.1
B1	27	3.17	5.4
B2	49	4.08	4.3
B3	175	2.53	3.3

The general character of the relation with spectral type is the same whether we consider maximum or mean intensity. The strong-

[1] *Popular Astronomy*, **34**, 7, 1926.

est lines occur in O-type stars and the weakest in subdivision B3. The decline per one-tenth of a spectral class from O to B2 is comparatively small, while from B2 to B3 it is very pronounced.

The dispersion in intensity within each spectral subdivision is considerable. Although there can be no doubt of the reality of progression with spectral type, it is evident that regional effects are the most powerful factors in determining the intensity of detached K. It is probably for this reason that the strongest individual lines do not occur in spectral type O. The four stars having the strongest detached lines known to me (intensity 9 or more) are given in Table IX.

The first star is of spectral type Bo; the others are B2. The great intensity of the K line in H.D. 212455 at a distance of about

TABLE IX

STARS WITH EXCEPTIONALLY STRONG DETACHED LINES

Star	α 1900	δ 1900	Mag.	Sp.	Dist.	Int.
9 Camelop.	4^h44^m1	$+66°10'$	4.1	Bo	270	9.3
62 χ^2 Orionis	5 58.1	20 08	4.5	B2p	180	13.0
9 Cephei	21 35.2	61 38	4.7	B2p	200	9.0
H.D. 212455	22 19.3	+54 47	8.2	B2	1000	15.0

1000 parsecs might perhaps tend to shake the suggestion, made above, that the lines grow fainter for distances greater than 500 parsecs. Too much weight should not be attached to this single star, however, particularly because of the regional effects, but also because of the uncertainty in spectral type. Mr. Joy suggests that the type is more nearly B3, which would reduce the distance to about 750 parsecs. Uncertainty in the adopted absolute magnitude of -1.2 may easily bring this value down to 500 parsecs.

The relation between spectral type and intensity can be interpreted only as a real effect of stellar radiation or temperature. It cannot be due to the greater average distance of the more luminous early-type stars, since the same relation exists for the maximum intensities of each spectral subdivision. As we have seen before, these maximum intensities refer in all cases to very nearly the same distance, 500 parsecs. We are justified, therefore, in assuming that the figures in the last column of Table VIII are free from any effects

due to distance, and their progression with spectral type must be due to the stars themselves.

Calcium lines in later spectral subdivisions of spectral type B.—Eddington[1] has attached some importance to the spectroscopic binary 66 Eridani,[2] of type B9, which at maximum separation of the two components should show a stationary detached line. No such line having an intensity more than 0.2 mag. below the continuous spectrum has been observed on any of our plates, a result verified by means of tracings obtained with the thermoelectric photometer.

Other spectroscopic binaries of types B5–A0, with large orbital velocities, have been observed by J. S. Plaskett.[3] The K line was measured in most of these stars, but no such abnormality as the appearance of an undisplaced line was recorded. Some of these stars are faint eclipsing variables at distances of the order of 300 parsecs or more. These results support the view that the detached lines disappear rather abruptly at subdivision B3—another argument in favor of the idea that the radiation of the stars influences the intensity of detached lines.

In type B3, however, some stars (like 16 Lacertae[4]) have detached lines, while others (like π^5 Orionis[5]) have stellar lines only. Various observers have suspected that in some stars detached lines and stellar lines occur simultaneously. The most reliable cases of this nature are σ Aquilae[6] and H.R. 8803,[7] both of type B3.

In order to find whether detached and stellar lines may coexist in stars of spectral type B5, I obtained a number of spectrograms with the Bruce spectrograph of the binary 2 Lacertae, the orbit of which was worked out by R. H. Baker[8] without reference to the

[1] *Loc. cit.*

[2] E. B. Frost and O. Struve, *Astrophysical Journal*, **60**, 313, 1924.

[3] *Publications of the Dominion Astrophysical Observatory, Victoria*, **1**, 138, 141, 145, 1919; **2**, 142, 1922.

[4] O. Struve and N. Bobrovnikoff, *Astrophysical Journal*, **62**, 139, 1925.

[5] This results from Mr. Lee's original measures. See *Astrophysical Journal*, **64**, 20, 1926 (Remark 98).

[6] F. C. Jordan, *Publications of the Allegheny Observatory*, **3**, 189, 1916.

[7] S. L. Boothroyd, *Publications of the Dominion Astrophysical Observatory, Victoria*, **1**, 281, 1921.

[8] *Publications of the Allegheny Observatory*, **1**, 98, 1909.

calcium lines. The semi-amplitude of the velocity variation is 80.3 km/sec. for the first component and 98.8 km/sec. for the other. On only one of my plates are the two components sufficiently separated, and on that plate the detached line is easily visible between the two stellar components. The spectral type, however, appears to be B3 rather than B5. *He* λ 4121 is appreciably stronger than *Si* II λ 4128 and λ 4131. *He* λ 4471 is about twice as strong as *Mg* λ 4481. According to the specifications of Joy,[1] such a star should be classified as B3.

The case of 2 Lacertae seems thus to prove that detached and stellar lines may coexist in stars of type B3. In later subdivisions, only stellar lines occur.

TABLE X

INTENSITY OF K AND GALACTIC LATITUDE

GAL. LAT.	O			Bo			B1			B2			B3		
	Mag.	No.	Int.	Mag.	No.	Int.	Mag.	No.	Int.	Mag.	No.	Int.	Mag.	No.	Int.
±(0°–10°)	5.8	18	4.3	6.0	27	3.6	5.0	15	4.1	5.7	30	5.3	5.1	94	2.6
(10–20)	4.5	8	3.4	3.5	13	3.9	2.9	8	2.1	3.7	11	2.5	4.8	48	2.5
(20–30)	.....	.....	.....	2.0	2	1.0	3.3	3	1.0	3.3	3	1.3	4.5	21	2.3
(30–40)	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.0	1	4.0	5.1	7	2.7
(40–50)	.....	.....	.....	.....	.....	.....	4.0	1	3.0	2.0	1	2.0	5.0	3	1.7
(50–60)	.....	.....	.....	3.0	1	3.0	.....	.....	.....	1.5	2	0.5	5.0	1	1.0
(60–70)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.3	2	1.5
±(70–80)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.0	1	2.0

Intensity and galactic latitude.—In order to investigate effects of galactic concentration I have taken the mean intensities for belts of 10° width in galactic latitude. Table X shows the results for all stars subdivided according to spectral type.

To make the data more homogeneous I have applied corrections to the mean intensities which reduce them to the same apparent magnitude, 5.0. The corrections were taken from the smooth curve in Figure 2, the average apparent magnitudes being given in Table X. On account of the scantiness of the data it seemed desirable to combine the different spectral subdivisions. I reduced all intensities to subdivision Bo by applying the following corrections for spectral type: O, −0.2; Bo, 0.0; B1, +0.4; B2, +1.0; B3, +1.7.

It should be noted that the corrections for magnitude and spec-

[1] A. H. Joy, "Selected Physical Properties of Stars and Nebulae," *International Critical Tables*, **1**, 384, 1926.

tral type were derived from all stars, without respect to galactic latitude. But since nearly 85 per cent of our stars lie within 20° from the Milky Way, possible effects of galactic latitude upon the corrections can here be neglected.

The final results, reduced to apparent magnitude 5.0 and to spectral type B0, are shown in Table XI.

The values indicate that the lines are strongest in a belt of 20° along the galactic circle and that they are somewhat fainter in high latitudes. This would correspond to a slight galactic concentration of the calcium clouds.

Since the inclination between the galactic plane and the central plane of the local cluster of helium stars is well marked in Figure 1, I

TABLE XI

INTENSITY AND GALACTIC LATITUDE FOR ALL STARS

Gal. Lat.	No.	Mean Intensity
±(0°–10°)	184	4.5
(10 –20)	88	3.9
(20 –30)	29	3.7
(30 –50)	13	4.2
±(50 –90)	7	3.4

have constructed another diagram, assuming the central plane to be inclined by 14°, the co-ordinates of the pole in the new system being α 11^h40^m, δ +27°. The effects due to galactic concentration remain essentially the same. Regional effects may influence these results. The Cepheus and Orion regions both fall within 20° of the galactic circle, and their effects will partially balance each other. The data are not sufficient to investigate the existence of other regions of abnormal intensity.

Intensities of detached calcium lines in double stars.—If regional effects are the most important factors in defining the intensity of a detached line, we should expect that the components of physically connected double stars, observed separately, would show similar intensities. With this end in view I selected all stars earlier than B5 which are either known as double stars or may reasonably be supposed to be relatively near each other in space.

Table XII shows that the intensities of the components of double stars are practically identical. This holds for a range in intensity of from about 0 (for 50 ζ Orionis) to 6 (for λ and ϕ' Orionis). It will also be seen that neither a difference of 3.6 mag. in the brightness of the components nor a difference of 0.3 spectral class has the least influence upon the intensity of detached K. This probably means that in double stars the two components act as one body with respect to the calcium gas. In other words, absorption takes place

TABLE XII

INTENSITY OF DETACHED K IN DOUBLE STARS

Star	α 1900	δ 1900	Sp.	Mag.	Int.
H.D. 25638	3^h59^m1	+62°04′	Bo	6.8	3
H.D. 25639	3 59.1	+62 04	Bo	6.8	3
37 φ^1 Orionis	5 29.3	+ 9 25	Bo	4.5	5
39 λ Orionis br.	5 29.6	+ 9 52	O8	3.7	6
39 λ Orionis ft.	5 29.6	+ 9 52	B1	5.3	6
θ^2 Orionis prec.	5 30.4	− 5 27	O	6.8	1
43 θ^2 Orionis	5 30.5	− 5 28	O8	5.2	2
41 θ^1 Orionis	5 30.4	− 5 27	O7	5.4	2
44 ι Orionis	5 30.5	− 5 59	O8	2.9	2
50 ζ Orionis br.	5 35.7	− 2 00	Bo	2.0	1
50 ζ Orionis ft.	5 35.7	− 2 00	Bo	4.0	0
8 β Scorpii br	15 59.6	−19 32	B1	2.7	2
8 β Scorpii ft.	15 59.6	−19 32	B1	4.8	2
H.D. 170051	18 22.4	+26 23	B3	6.7	4
H.D. 170111	18 22.7	+26 23	B3	6.2	3

within a sphere the radius of which is large compared with the distance of the two components. Obviously, this result does not permit discrimination between the hypotheses of Eddington and of Plaskett; but it fixes a lower limit for the distance at which the radiation of an early-type star can produce absorption of the detached type. In the case of the two components of λ Orionis, for example, the angular separation is nearly 5″. The distance of this star from the sun, computed from spectral type and spectroscopic absolute magnitude, is 250 parsecs. The separation of the two components is, accordingly, of the order of 1000 astronomical units. We

may tentatively assume that the effective reach of stellar radiation in producing detached absorption lines is at least ten times larger—of the order of 10,000 astronomical units, or one-twentieth of a parsec.

II. A CALCIUM CLOUD IN CEPHEUS

Radial velocities.—Table XIII gives the radial velocities separately for each plate for the 36 stars in the Cepheus region. The velocities from stellar and detached calcium lines are given in separate columns. The results are summarized in Table XIV, which, in addition to the mean velocities derived from the data in Table XIII, also gives the radial components of the solar motion computed from $\alpha = 270°$, $\delta = +30°$, $V = 20.0$ km/sec. No correction was made for a K-term. The ninth and tenth columns of Table XIV give the residual radial velocities for the stars and the calcium cloud. The eleventh indicates the intensity of the detached K line, as determined at Mount Wilson and Yerkes Observatories.

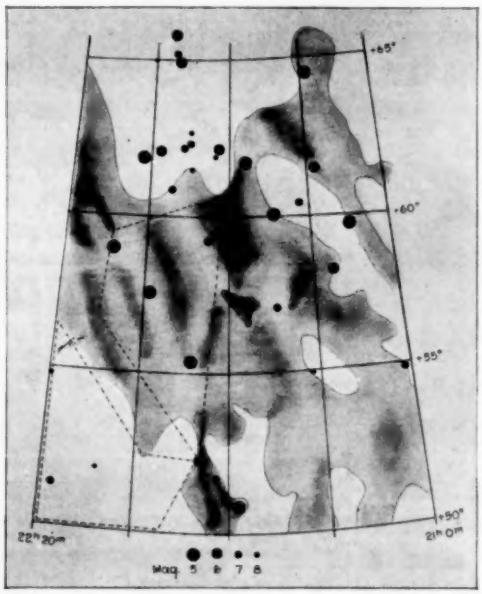


FIG. 4.—Map of region in Cepheus. The dots indicate the positions of all stars earlier than B5 which have been observed at Mount Wilson. The shaded areas indicate regions of obscuration of greater or less density. The broken lines show the two regions in which star counts have been made.

The number of spectrograms per star is admittedly too small to permit of a complete discussion. The probable error of one Yerkes plate is ±9 km/sec. The Mount Wilson plates were all measured twice, and their probable error is estimated to be about ±3 km/sec. In view of the scantiness of the material on velocities nothing more than suggestions can be made concerning systematic motions.

TABLE XIII

RADIAL VELOCITIES OF 36 STARS IN CEPHEUS REGION

STAR	MEAS. BY	DATE	RADIAL VELOCITY		QUAL.	REMARKS
			Star	*Ca*		
H.D. 200857....	S	1926 June 29.260	− 35.4	.....	v.p.	* Few, fair; *Ca* v. poor, faint
	S	1926 Sept. 15.209	− 31.2	−24.6	g	
Boss 5453.....	YO	1904 Apr. 15.906	− 14.8	− 2.7	v.g.	* Many v.g.; *Ca* fair
	YO	1904 Nov. 25.494	− 20.1	.....	v.p.	
	YO	1905 Apr. 7.931	− 14.7	.....	v.p.	
	YO	1918 July 1.777	− 10.0	.....	f	
	S	1926 June 28.299	− 7.4	− 8.0	g	
H.D. 203025....	MtW	.....	− 17.2	−19.4	.....	* Good; *Ca* v.g.; sp. triple; orbit: Sanford (*ASP*, **38**, 262, 1926)
H.D. 203374....	S	1921 Nov. 19.667	− 6.8	−25.3	g	* V. few; *Ca* fairly strong; hydrogen lines show emission in β and γ; Hδ and *He* are absent; *Mg* 4481 is indistinct; absence of *He* makes *Ca*H stand out very distinctly
	S	1926 June 28.338	+ 18.3	−14.1	g	
6 Cephei.....	YO	1905 May 8.854	− 14.9	.....	p	* Few poor; *Ca* poor; sp. bin.
	YO	1924 Aug. 9.662	− 25.0	.....	g	Bright lines give −9.2
	YO	1924 Aug. 11.680	− 41.1	.....	g	Bright lines give +2.0
	S	1926 June 30.248	− 48.5	−37.0	g	
H.D. 204116....	S	1926 June 29.444	− 5.0	− 8.1	p	* Many fair; *Ca* weak; probably sp. bin.
	S	1926 Aug. 23.558	− 40.2	−23.8	g	
H.D. 204150....	S	1926 Aug. 23.199	− 36.7	− 8.4	g	* Few fair; *Ca* faint
β Cephei.....	YO	.....	− 9.1	.....	.....	* Many v. g.; *Ca* absent or extremely faint; sp. bin.; velocity of system from many Yerkes plates
	S	1926 July 24.337	+ 12.0	.....	.....	
Boss 5535.....	S	1914 Oct. 4.736	− 16.5	(− 1.6)	f	* Many fair; *Ca* fair
	MtW	1917 July 4.963	− 9.9	.....	g	
	MtW	1917 Sept. 7.891	− 4.5	.....	f	
	S	1926 June 30.267	− 18.0	−16.2	g	
H.D. 205196....	S	1926 June 30.322	− 20.4	(−81.6)	f	* Many good; *Ca* v. faint or absent
	S	1926 July 22.244	− 21.5	(−39.3)	g	
9 Cephei.....	YO	1909 Aug. 6.894	− 19.2	(− 0.7)	v.g.	* Many good; *Ca* good
	YO	1909 Aug. 16.715	− 16.5	.....	p	
	YO	1909 Sept. 10.657	− 17.2	.....	p	
	YO	1909 Oct. 25.633	− 9.0	(+10.8)	g	
	S	1926 June 30.433	− 16.2	−21.9	g	
	S	1926 July 10.292	− 5.0	.....	p	
	S	1926 July 16.131	− 8.6	−29.3	f	
	S	1926 July 23.384	− 12.9	−21.0	g	
Boss 5565.....	YO	1906 Sept. 24.676	− 24.1	.....	p	* Few poor; *Ca* v.g.; sp. bin.; velocity of system, according to J. S. Plaskett, is −1.0 km/sec.; *Ca* gives −18.5 km/sec.
	S	1926 June 30.457	−113.6	−19.0	g	
H.D. 206327....	S	1926 Aug. 21.426	− 37.1	(−62.9)	g	* Many good; *Ca* faint

TABLE XIII—*Continued*

Star	Meas. By	Date	Radial Velocity		Qual.	Remarks
			Star	*Ca*		
80 π^2 Cygni.....	YO	1903 July 11.750	− 8.1	.....	g	* Few fair; *Ca* fair; sp. bin.
	YO	1903 Aug. 8.710	− 7.4	.....	f	
	YO	1903 Sept. 18.601	− 7.7	.....	g	
	YO	1906 Sept. 10.707	− 17.6	.....	g	
	YO	1911 Aug. 18.684	− 25.1	−25.6	v.g.	
	YO	1911 Aug. 28.658	− 31.2	−38.2	g	
H.D. 206773....	S	1921 Sept. 22.752	− 1.0	.....	f	* Few v. poor; *Ca* v. faint and diffuse
	S	1924 June 10.965	− 3.6	−16.1	g	
	S	1926 June 28.404	− 40.7	− 9.4	g	
	S	1926 July 23.219	− 24.6	−26.0	g	
H.D. 207198....	S	1926 June 30.488	− 24.0	− 9.8	g	* Many good; *Ca* v.g.
H.D. 207308....	S	1926 July 22.367	− 25.8	−28.0	g	* Few v. poor; *Ca* v. broad
H.D. 207329....	S	1926 July 24.403	− 66.0	−21.6	f	* Few fair; *Ca* fair
H.D. 207538....	S	1926 July 23.457	− 12.6	−13.2	g	* Many good; *Ca* fair
	S	1926 Sept. 16.396	− 14.2	−26.4	g	
H.D. 207793....	S	1926 June 30.394	− 57.8	−16.4	g	* Few v. poor; *Ca* v.g.
H.D. 208095....	YO	1913 Aug. 1.752	+ 80.2	.....	f	* Few fair; *Ca* absent; sp. bin.; sp. type B5
	YO	1924 Dec. 9.628	+ 1.1	.....	g	
	YO	1924 Dec. 22.594	− 4.6	.....	p	
	S	1926 July 23.169	− 33.6	.....	g	
H.D. 208106....	S	1926 Aug. 23.397	− 23.7	−10.2	g	* Few poor; *Ca* good
H.D. 208185....	S	1926 Aug. 22.349	− 16.0	(−36.8)	f	* Many good; *Ca* poor
H.D. 208218....	S	1926 Aug. 22.156	− 22.1	− 9.4	g	* Many good; *Ca* v. faint
H.D. 208392....	S	1926 Aug. 22.484	− 14.2	− 8.8	g	* Few v. poor; *Ca* v.g.
	S	1926 Sept. 16.158	− 31.1	−12.2	g	
Boss 5642.....	S	1922 Aug. 5.900	−113.5	(−22.7)	g	* Few poor; *Ca* v.g.; sp. bin.; on Aug. 5, 1922, a second component was measured at +49.2 km/sec.; mean velocity as measured by Plaskett, −16.5 km/sec. *Ca* −17.0 km/sec.
	MtW	1923 Aug. 18.812	+ 73.8	.....	g	
	MtW	1923 Sept. 20.799	+ 12.4	.....	g	
	MtW	1923 Oct. 22.640	+ 18.1	(−30.0)	g	
	MtW	1923 Nov. 20.696	− 27.0	(+ 8.0)	g	
	S	1926 July 22.455	− 21.2	− 7.6	g	
	S	1926 Sept. 15.123	− 28.8	− 9.0	g	
H.D. 208904....	S	1926 July 23.359	− 17.1	−20.7	g	* Few fair; *Ca* good but faint
H.D. 208905....	S	1926 Aug. 22.218	− 10.4	(+38.3)	g	* Few fair; *Ca* v. faint
H.D. 208947....	S	1926 July 23.275	− 17.6	−19.6	g	* Few fair; *Ca* good
H.D. 209339....	MtW	1912 Aug. 4.908	− 16.9	.....	f	* Few fair; *Ca* good
	MtW	1912 Dec. 18.610	− 19.0	.....	g	
	MtW	1913 Aug. 12.988	− 28.7	(−42.2)	g	
	S	1919 Aug. 16.848	− 4.3	−12.5	f	
	S	1926 July 24.490	− 23.4	− 7.6	f	
14 Cephei.....	S	1922 June 16.765	+ 10.3	−12.9	v.g.	* Few v. poor; *Ca* v.g.
	S	1922 July 3.794	− 16.4	(−42.6)	f	
	S	1926 June 24.267	+ 22.9	.....	p	
	S	1926 Aug. 8.385	+ 22.7	(− 5.6)	f	
H.D. 209961....	S	1926 Sept. 16.240	− 11.6	− 1.8	g	* Few good; *Ca* good; sp. bin.; velocity of system, according to R. K. Young, is −17.8 km/sec. *Ca*, +1.5 km/sec.

TABLE XIII—*Continued*

Star	Meas. By	Date	Radial Velocity		Qual.	Remarks
			Star	*Ca*		
19 Cephei.....	YO	1913 June 27.869	− 15.0	.....	g	* Many fair; *Ca* good; sp. bin.; Plaskett gives for radial velocity −10.9 km/sec. *Ca*, −12.8 km/sce.
	YO	1913 July 9.853	+ 7.6	.....	p	
	YO	1913 Sept. 1.808	− 19.1	.....	p	
	YO	1920 June 25.844	− 43.0	.....	f	
	YO	1920 July 23.801	− 30.9	.....	f	
	S	1923 Aug. 19.729	+ 13.1	− 5.2	g	
	S	1923 Aug. 19.729	+ 13.1	− 5.2	g	
H.D. 210809....	S	1926 Sept. 15.362	− 81.4	−20.7	g	* Many good; *Ca* good
λ Cephei.....	YO	1904 Oct. 28.606	− 51.1	.....	g	* Few v. poor; *Ca* good; Plaskett gives for radial velocity −73.6 km/sec. *Ca*, −14.4 km/sec.
	YO	1904 Nov. 1.683	− 93.5	.....	g	
	YO	1908 Aug. 24.733	− 62.3	.....	g	
	YO	1918 Sept. 13.625	− 74.4	−12.1	f	
H.D. 212044....	S	1921 Nov. 20.663	− 3.1	−14.6	g	* Few poor; *Ca* good
	S	1924 July 17.970	+ 1.9	−14.0	g	
H.D. 212222....	S	1926 Sept. 16.300	− 24.6	−14.4	g	* Few good; *Ca* good
H.D. 212455....	S	1926 Aug. 23.427	− 54.7	−13.5	g	* Few poor; *Ca* v.g.

NOTE TO TABLE XIII

In the second column my own measures are indicated by the letter "S"; "MtW" denotes measures by various Mount Wilson observers, and "YO" stands for earlier Yerkes measures. The date is given in Greenwich Civil Time, except for plates taken before January 1, 1925, for which Greenwich Mean Time is given. The velocities from the calcium lines were not used in forming the mean velocity of the star. Measures which for any reason seemed to be unreliable are in parentheses and were not used in the discussion. Remarks in the last column concern the character of stellar (*) and calcium (*Ca*) lines.

The velocities of the stars in the Cepheus region do not exhibit any very striking systematic effects (Fig. 5). It is quite possible that some of these stars are in reality spectroscopic binaries. It need not surprise us, therefore, that the two stars H.D. 207329 and H.D. 207793 show large negative velocities. Remarks are added to Table XIII concerning a few stars, definitely known or suspected to be spectroscopic binaries.

The calcium velocities differ in many cases very considerably from the stellar velocities. In general, the residual velocities from the calcium lines are small. This supports Plaskett's earlier result that the calcium clouds have small velocities with respect to the stellar system. Between declinations $+50°$ and $+60°$, negative values predominate, the mean residual velocity being -4.0 km/sec., with a probable error of ± 0.8 km/sec. North of declination $+60°$, positive values are more frequent, while in the same region the stellar residual velocities are mostly negative.

Intensities of the detached K line in the Cepheus region.—The intensities plotted in Figure 7 show, as previously mentioned, that the calcium lines are unusually strong in practically the whole Cepheus

TABLE XIV

SUMMARY OF RADIAL VELOCITIES

STAR	α 1900	δ 1900	SP.	MAG.	RADIAL VEL.		SUN	VEL. RESIDUAL		INTENSITY
					Star	*Ca*		Star	*Ca*	
H.D. 200857	21h 1m0	+45°51′	B2	7.0	−33.3	−24.6	+15.0	−18.3	− 9.6	3
Boss 5453	21 9.3	+59 35	B2	5.5	−13.4	− 5.4	+14.5	+ 1.1	+ 9.1	5
H.D. 203025	21 14.6	+58 10	B3	6.2	−17.2	−19.4	+14.4	− 2.8	− 5.0	8
H.D. 203374	21 16.7	+61 25	Bop	6.4	+ 5.8	−19.7	+14.2	+20.0	− 5.5	6
6 Cephei	21 17.3	+64 27	B3p	5.0	−32.4	−37.0	+13.8	−18.6	−23.2	2
H.D. 204116	21 21.4	+54 57	Bo	7.7	−22.6	−16.0	+14.3	− 8.3	− 1.7	2
H.D. 204150	21 21.6	+60 23	B3	7.4	−36.7	− 8.4	+14.1	−22.6	+ 5.7	2
β Cephei	21 27.4	+70 7	B1	3.1	− 9.1	.....	+13.0	+ 3.9	.....	0
Boss 5535	21 28.3	+60 1	Bo	5.3	−12.2	−16.2	+14.0	+ 1.8	− 2.2	6
H.D. 205196	21 28.6	+57 4	Bo	7.1	−21.0	.....	+14.0	− 7.0	.....	4
9 Cephei	21 35.2	+61 38	B2p	4.7	−13.1	−24.1	+13.7	+ 0.6	−10.4	9
Boss 5565	21 35.9	+57 2	Oe5	5.6	− 1.0	−19.0	+14.2	+13.2	− 4.8	7
H.D. 206327	21 36.3	+61 6	Oe5	8.5	−37.1	.....	+13.7	−23.4	.....	1
80 π1 Cygni	21 38.6	+50 44	B3	4.6	−16.2	−31.9	+14.0	− 2.2	−17.9	4
H.D. 206773	21 39.3	+57 17	Bop	6.7	−17.5	−17.2	+13.6	− 3.9	− 3.6	4
H.D. 207198	21 42.2	+61 59	B2	5.8	−24.0	− 9.8	+13.4	−10.6	+ 3.6	8
H.D. 207308	21 42.9	+61 50	B2	7.7	−25.8	−28.0	+13.4	−12.4	−14.6	4
H.D. 207329	21 43.1	+51 39	B2	7.3	−66.0	−21.6	+13.9	−52.1	− 7.7	0
H.D. 207538	21 44.6	+59 14	B3	6.9	−13.4	−19.8	+13.3	− 0.1	− 6.5	2
H.D. 207793	21 46.5	+52 14	B2	6.4	−57.8	−16.4	+13.7	−44.1	− 2.7	6
H.D. 208095	21 48.8	+55 20	B5	5.4	+10.8	.....	+13.5	+24.3	.....	.....
H.D. 208106	21 48.9	+61 27	B3	7.9	−23.7	−10.2	+13.3	−10.4	+ 3.1	7
H.D. 208185	21 49.5	+62 38	B3	7.5	−16.0	.....	+13.1	− 2.9	.....	4
H.D. 208218	21 49.7	+62 13	B1	6.5	−22.1	− 9.4	+13.1	− 9.0	+ 3.7	5
H.D. 208392	21 50.9	+62 8	B3	6.9	−22.6	−10.5	+13.0	− 9.6	+ 2.5	8
Boss 5642	21 52.9	+64 52	B2	5.7	−12.3	− 8.3	+12.7	+ 0.4	+ 4.4	5
H.D. 208904	21 54.3	+65 9	B3	7.4	−17.1	−20.7	+12.7	− 4.4	− 8.0	3
H.D. 208905	21 54.3	+60 49	B3	6.7	−10.4	.....	+13.0	+ 2.6	.....	3
H.D. 208947	21 54.7	+65 41	B3	6.1	−17.6	−19.6	+12.7	− 4.9	− 6.9	7
H.D. 209339	21 57.6	+62 0	Bo	6.2	−18.5	−10.0	+12.8	− 5.7	+ 2.8	6
14 Cephei	21 58.7	+57 31	Bo	5.3	+ 9.9	−12.9	+13.0	+22.9	+ 0.1	7
H.D. 209961	22 2.0	+47 45	B3	6.0	−17.8	− 1.8	+12.9	− 4.9	+11.1	7
19 Cephei	22 2.1	+61 48	Oe5	5.2	−14.6	− 5.2	+12.7	− 1.9	+ 7.9	7
H.D. 210809	22 7.9	+51 56	B2	7.5	−81.4	−20.7	+12.6	−68.8	− 8.1	8
λ Cephei	22 8.1	+58 56	Od	5.2	−70.3	−12.1	+12.5	−57.8	+ 0.4	6
H.D. 212044	22 16.4	+51 21	B2p	6.9	− 0.6	−14.3	+12.4	+11.8	− 1.9	6
H.D. 212222	22 17.6	+41 36	B3	6.1	−24.6	−14.4	+12.2	−12.4	− 2.2	3
H.D. 212455	22 19.3	+54 44	B2	8.2	−54.7	−13.5	+12.2	−42.5	− 1.3	15

NOTE TO TABLE XIV

For four spectroscopic binaries with determined orbits I have given the velocity of the system, as shown in Table XIII. The other radial velocities are the means of the observations listed in Table XIII.

region. This suggests at once that no direct relation can exist between calcium cloud and obscuring nebula. By grouping the stars into three classes, I find for 19 stars situated in regions where the stellar distribution is normal a mean intensity of 5.1 units; for 11 stars in obscured regions, a mean intensity of 4.8; and for 8 stars in regions where the obscuring nebulae are especially dense, a mean of

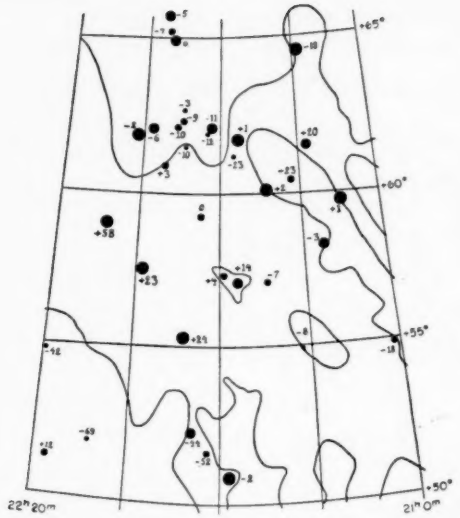


FIG. 5.—Map of region in Cepheus showing the residual radial velocities of stars of spectral type earlier than B5.

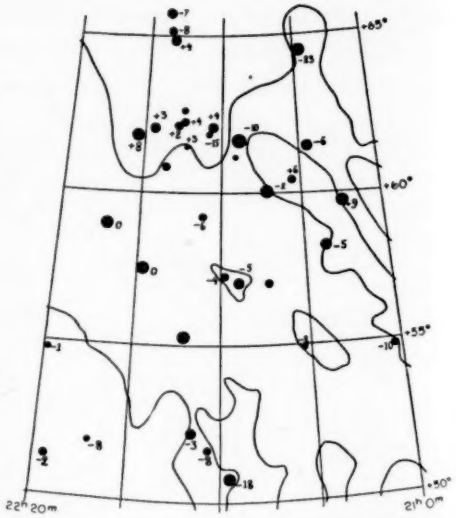


FIG. 6.—Map of region in Cepheus showing residual radial velocities from detached calcium lines.

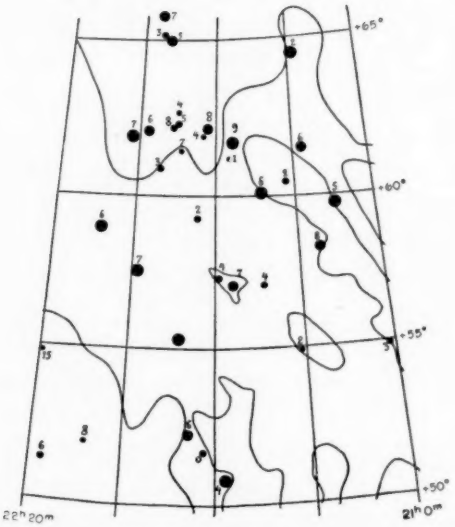


FIG. 7.—Map of region in Cepheus showing the intensities of detached calcium lines. One star was found to be of spectral type later than B3 and the corresponding intensity was omitted.

4.0. If there is any relationship at all, the obscured regions are correlated with relatively weak detached lines.[1]

Grouping the stars according to apparent magnitude makes it possible roughly to establish the distance at which the calcium lines appear particularly strong. Table XV gives the mean intensities.

The comparatively large value in the last line is due to H.D. 212455, which has an unusually strong K line (intensity 15). If this star were excluded, the last value would be 3.2. The lines appear to

TABLE XV

INTENSITY AND APPARENT MAGNITUDE IN CEPHEUS REGION

App. Mag.	No. of Stars	Mean Int.
3–4	1	0.5
4–5	2	6.5
5–6	11	5.5
6–7	13	5.4
7–9	12	4.4

be strongest, on the average, for apparent magnitude 5, which corresponds to a distance of about 250 parsecs. The figures indicate a small decline in intensity for the fainter stars. In any case, we are justified in assuming that the calcium cloud in Cepheus begins at a distance of about 250 parsecs.

The obscuring nebula.—Although no very definite relation exists between the intensities of detached lines and the location of stars with respect to regions of obscuration I have tried to estimate the distance of the dark nebula, for comparison with the distance found above for the calcium cloud.

For this purpose I have made star-counts in two regions; one of 16.5 square degrees is situated in the galactic star cloud around

[1] I have since made similar determinations for two other regions photographed by Professor F. E. Ross with long exposures. The results are as follows:

Region	Orion		Perseus	
	Av. Int.	No. Stars	Av. Int.	No. Stars
Normal	2.5	9	2.8	6
Obscured	2.2	3	.....	.....
Br. Nebula	2.2	17	3.2	7

α 22^h10^m, δ $+52°$, while the other, including 19.8 square degrees, lies in a region of obscuration, around α 21^h55^m, δ $+58°$ (see Fig. 4). The counts were made separately for each spectral type, with the aid of the *Draper Catalogue*. For counting stars fainter than the eighth magnitude, I obtained a number of plates with different exposure times, using a wide-angle 2-inch lens and the 10-inch Cooke photographic telescope of the Mount Wilson Observatory. The limiting magnitudes were determined from similar exposures on

TABLE XVI

NUMBER OF STARS PER SQUARE DEGREE DOWN TO EVERY GIVEN MAGNITUDE

APP. MAG.	O, B		A		F		G		K, M	
	I*	II*	I	II	I	II	I	II	I	II
1.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.5	.....	0.15	.....	0.05	.....	0.05	.....	.....	.....	0.05
6.5	0.12	.30	0.06	.10	.....	.10	.....	.....	0.06	.05
7.5	.24	.50	0.24	0.40	.....	.15	.....	0.05	.06	.10
8.5	.71	.80	1.24	1.21	0.29	.45	.....	.05	0.41	.25
9.5	.89	.85	3.30	1.97	.70	.65	0.18	.30	1.11	.60
10.5	.89	.85	3.48	1.97	.76	.65	.18	.50	1.34	.95
11.5	0.95	0.85	3.48	1.97	0.76	0.65	0.18	0.50	1.46	0.95

* Region I is situated in the galactic star cloud, while Region II lies in an area of obscuration.

Selected Area 18, the photographic magnitudes of the comparison stars having been supplied by Mr. Seares, and independently checked by means of Harvard magnitudes.[1] Systematic differences between Mount Wilson and Harvard magnitudes can be neglected for the present purpose. On each plate I counted all stars down to the limiting magnitude, within the areas described. Table XVI gives the total number of stars per square degree brighter than each given magnitude, as counted from the *Draper Catalogue*.

For types O, B, and A the effect of obscuration begins to be noticeable at apparent magnitude 8, while for F stars it begins at magnitude 9. For the later types the effect lies below the limit for which the *Draper Catalogue* is complete. From the estimates made

[1] *Annals of the Harvard College Observatory*, **101**, 1918.

for types B, A, and F it appears that the distance of the nearer edge of the dark nebula is about 400 parsecs.

From the star-counts made without respect to spectral type, I find numbers of stars (per square degree) brighter than each given apparent magnitude as shown in Table XVII.

The values of log B_m are plotted in Figure 8. For the star cloud my values agree fairly well with those of Seares, Van Rhijn, Joyner,

TABLE XVII

NUMBER OF STARS PER SQUARE DEGREE

App. Mag.	Region in Milky Way			Region of Obscuration			Method
	B_m	log B_m	Resid.*	B_m	log B_m	Resid.*	
5.5.....	0.00	−1.	+0.12	0.30	−0.52	+0.60	*H.D. Cat.*
6.3.....	0.18	−0.75	+ .01	0.35	−0.46	+ .30	2-inch
6.5.....	0.24	−0.62	+ .05	0.55	−0.26	+ .41	*H.D. Cat.*
7.4.....	0.24	−0.62	− .36	0.66	−0.18	+ .08	2-inch
7.5.....	0.54	−0.27	− .05	1.20	+0.08	+ .30	*H.D. Cat.*
8.3.....	0.70	−0.15	− .29	1.67	+0.22	+ .08	2-inch
8.5.....	2.65	+0.42	+ .19	2.71	+0.43	+ .20	*H.D. Cat.*
9.5.....	1.82	+0.26	− .41	3.70	+0.57	− .10	2-inch
10.6.....	14.1	+1.15	.00	8.3	+0.92	− .23	2-inch
12.0.....	64.5	+1.81	+ .07	27.5	+1.44	− .30	10-inch
12.3.....	110.	+2.04	+ .17	59.0	+1.77	− .10	2-inch
12.6.....	117.	+2.07	+ .07	65.8	+1.82	− .18	10-inch
13.7.....	210.	+2.32	− .13	95.4	+1.98	− .47	10-inch
14.8.....	514.	+2.71	− .17	260.	+2.42	− .46	10-inch
15.7.....	1110.	+3.05	−0.17	508.	+2.71	−0.51	10-inch

* The residuals give the differences between my values of log B_m and those of Seares, Van Rhijn, Joyner, and Richmond (*Mt. Wilson Contr.*, No. 301; *Astrophysical Journal*, **62**, 362, 1925 [Table XVII]; gal. lat., 0°).

and Richmond.[1] In the obscured region the number of bright stars is greater than normal. Table XVI shows that this is due almost entirely to the large number of B-type stars in this region. The effect of the cloud begins to be noticeable at about apparent magnitude 9.5 and reaches its full value at magnitude 11. Between magnitudes 11 and 15 the two curves run parallel, with a displacement of about 1 mag.

Assuming with Seares[2] that the mean parallax of stars of apparent magnitude 9.5 is about 0".003, I find the distance at which the obscuring nebula begins is 330 parsecs.

[1] *Mt. Wilson Contr.*, No. 301; *Astrophysical Journal*, **62**, 362, 1925 (Table XVII).

[2] *Mt. Wilson Contr.*, No. 281; *Astrophysical Journal*, **60**, 59, 1924.

A greater distance, of 500–600 parsecs, is obtained from a Russell diagram of stars belonging to the open cluster around Boss 5565 (α 21^{h}36^m, δ +57°). Lundmark[1] places this object at a distance of about 1000 parsecs. It is possible, however, that the magnitudes of the stars involved in the bright nebula are affected by obscuration.

In any case, it seems certain that the obscuring masses lie farther away than the beginning of the calcium cloud. The existence of

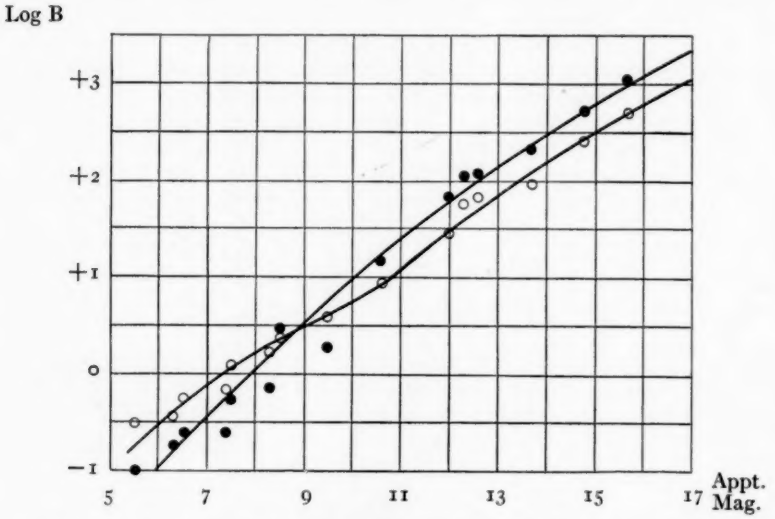


FIG. 8.—Logarithm of the number of stars brighter than apparent magnitude m in the galactic star cloud (dots) and in the region of obscuration (open circles).

strong detached lines in Boss 5565 and in other stars at distances of at least 500 parsecs suggests that the calcium cloud merges into the obscuring nebula.

Since the region of strong calcium lines also extends over portions of the Milky Way where the distribution of stars is normal, we conclude that the calcium cloud is transparent, except, of course, for monochromatic radiation.

It is perhaps significant that in Orion, as well as in Cepheus, the presence of nebulous matter seems to favor comparatively weak detached lines; the strongest lines occur in regions devoid of nebu-

[1] *Meddelanden från Astronomiska Observatorium, Upsala,* No. 12, 1926; *Populär Astronomisk Tidskrift,* Häfte 1, 1926.

lous matter. In both cases the calcium cloud merges into the nebula, and in Orion it partly coincides in space with the nebula.

III. CONCLUSIONS

The results given in this paper support the hypothesis that detached lines originate in interstellar clouds of calcium matter. This is evidenced by the radial velocities from the detached lines, which have no relation to the velocities of the stars; also by the increase in intensity for the hottest stars, which is contrary to the expected behavior of stellar lines of ionized calcium. The existence of regional effects, as well as of effects due to distance, also supports this hypothesis.

The increase of intensity with distance was predicted by Eddington's hypothesis, and found to exist for distances up to 500 parsecs from the sun. Quantitatively, the observed increase in intensity depends upon the calibration of the arbitrary scale. The lines nearly double in strength for a doubling of the distance. This is in fair agreement with Eddington's deductions.

On the other hand, the decrease in intensity for distances greater than 600 parsecs, if real, would be contrary to Eddington's hypothesis. It will be interesting to obtain a larger amount of material for stars fainter than the seventh magnitude, which would settle this point definitely.

In favor of Eddington is the fact that the detached lines occur in the vast majority of stars of spectral type not later than B3. Table V shows that in the galactic plane interstellar calcium may be observed at distances of over 1000 parsecs. In galactic latitudes greater than 30° the calcium lines appear to be a little fainter. Spectroscopic parallaxes of the stars included in the last five lines of Table X show that in such directions interstellar calcium exists at distances of at least 150 parsecs. Since in the higher galactic latitudes B stars of distances greater than 150 parsecs are very infrequent, we have no information concerning the distribution of interstellar calcium beyond this distance. The possibility that the calcium clouds are distributed in an oblate spheroid is, therefore, not excluded.[1] Nevertheless, the existence of detached lines in stars

[1] I am indebted for this suggestion to Professor F. H. Seares.

situated far from the Milky Way and at distances of the order of over 150 parsecs suggests that the distribution of the calcium clouds in our stellar system differs essentially from the distribution of all other known types of nebulae.

The sudden disappearance of the detached lines beyond spectral type B3 seems to me, however, to be fatal to Eddington's hypothesis in its present form. All the information available at present indicates that detached K does not exist in subdivisions later than B3. The sudden drop in intensity begins at about B2, and seems to show that stellar radiation is a factor in determining the intensity of detached K. Perhaps Eddington's hypothesis could be modified in such a way as to account for this effect.

On the other hand, my results are not contrary to the original hypothesis of Plaskett. If absorption occurs only in the vicinity of hot stars enveloped in calcium clouds, the effect of spectral type is at once explained. The effect of distance requires only that we assume a greater concentration of calcium clouds near the boundaries of the local cluster of helium stars. Under such conditions the probability of a star being enveloped in a dense cloud increases with distance. The same thing is probably true for dark and bright galactic nebulae, and therefore need not surprise us. Neither would it be surprising if the clouds should be less dense beyond the boundaries of the local cluster. Stars situated at distances greater than 600 parsecs would again have a small chance of being enveloped in a calcium cloud—and the mean intensity will thus be smaller. This hinges, of course, on the assumption that ionization and absorption are limited to a shell around the star and that all other intervening calcium masses are left in a state in which they do not appreciably absorb the light of the star.

Present observational material does not make it possible to accept definitely either hypothesis. It is therefore advisable to accept the effects due to distance, spectral type, region in the sky, etc., as properties of the calcium clouds without, at present, attempting to specify the physical explanation.

I am greatly indebted to Director W. S. Adams for his kindness in granting me the use of the 60-inch reflector and other instru-

ments of the Mount Wilson Observatory. To him, as well as to Directors E. B. Frost, J. S. Plaskett, and R. G. Aitken, I am also indebted for generous permission to use earlier spectrograms taken by themselves or by their associates. Grateful acknowledgment is likewise made to members of the staff of the Mount Wilson Observatory for material and helpful suggestions relating to the investigation. The reductions were made in part by Miss M. Wiberg and Miss M. Fretz at Mount Wilson, and by Miss L. D. Cable and Madame L. Struve at the Yerkes Observatory. The investigation was carried out under a grant from the International Education Board of New York.

YERKES OBSERVATORY
January 1927

NOTE ADDED APRIL 14

Since this paper was written Miss Payne and Mr. Hogg at the Harvard College Observatory have undertaken the determination of the intensity of K on a spectrogram of Sirius taken at the Yerkes Observatory. Their value is about 0.6 mag., while my estimate would be about 8 units or 0.8 mag. Similarly, their value for Vega would be 0.75 mag., while I have used 1.0 mag. The differences are not large and are fully discussed by Miss Payne and Mr. Hogg (*Harvard College Observatory Circular 304*, in press). The authors also discuss the difference in the results between slit spectrographs and objective-prism instruments, for narrow lines. For further details the reader is referred to the original publication. I have the impression that the order of magnitude of my estimates is correct, but it is possible that they should be reduced by something like 20 or 25 per cent. I am obliged to Miss Payne for having communicated to me her results in advance of publication.

CARL RUNGE

We record with great regret the death, on January 3, 1927, of Carl Runge, emeritus professor of applied mathematics at the University of Göttingen. Eminent for his researches in spectroscopy, as well as in pure and applied mathematics, Professor Runge had been associated with this *Journal* as a contributor, and since 1903 as a collaborator. We shall print an appropriate sketch of his life and scientific work in a future number of this *Journal*.